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OAK RIDGE NATIONAL LABORATORY

THE FIRST FIFTY YEARS

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PROLOGUE

One of the world's premier scientific research centers, Oak Ridge National Laboratory represents a marriage between science and industrial technology forged for national defense during the throes of global war. Currently operated by Martin Marietta Energy Systems, it is the oldest national laboratory on its original site, site of the world's oldest nuclear reactor, and home to the Department of Energy's largest and most diversified multiprogram laboratory.

As a government-sponsored institution operated by a private corporation to advance energy science and technology in partnership with universities and industries, Oak Ridge National Laboratory is a unique experiment in scientific and governmental administration. Because solutions to energy and environment problems are found as much in engineering and applied technology as in basic science, the Laboratory offers a vital link between the two and carries an avowedly semi-industrial appearance clothed by an academic predisposition.

Celebrating fifty years of service to the United States in 1993, Oak Ridge National Laboratory has changed the history of the nation and the world. As a remarkable and sometimes bewildering complex of sophisticated industrial, science, and educational activities in an isolated rural setting, the Laboratory is also a microcosm of the United States, reflecting shifts in national and global concerns during the past fifty years.

Initially composed of 1500 scientists and support staff working with a graphite reactor in primitive wooden frame buildings during World War II, the Laboratory passed through many transitions during the following fifty years. It survived postwar retrenchments by focusing on nuclear science and the development of nuclear energy for peaceful uses. In the 1960s, it became the first national laboratory to turn to research tied only tangentially to nuclear energy, and during the 1970s it expanded its research, in accord with shifting national priorities, to encompass all forms of energy and their impacts on the environment. During the 1980s, it became a multiprogram laboratory of the Department of Energy, leading broad research initiatives responsive to national needs. By its fiftieth anniversary, Oak Ridge National Laboratory had emerged as a premier global research center for issues related to energy, environment, and basic science and technology.

Currently employing about 4500 people, including many scientists recognized as international experts in their fields, the Laboratory's research agenda ranges from global warming to energy conservation to superconductivity to tropical rain forest depletion and nuclear medicine. It is committed to improving national science education and to speeding the transfer of its technological developments to the commercial marketplace.

Since 1943, scientists and technicians at Oak Ridge National Laboratory have confronted issues vital to human life and its environment. Established to create nuclear weapons of unprecedented destructive power, the supreme paradox of its history is its subsequent contributions to energy, environment, health, and the economy. Today, millions of people each year benefit from research and development pioneered at the Laboratory.

During the next fifty years, the Laboratory is likely to expand its agenda to encompass the full array of scientific and technical issues facing the nation and world. In the process, it will further enhance its role as a national laboratory in service to America's--and the world's--scientific and technical needs. The Laboratory, in short, has a history worth noting and a future worth watching.

PREFACE

This history of the first fifty years of Oak Ridge National Laboratory was prepared to commemorate its golden anniversary in 1993. The Laboratory's historical committee provided direction and resources for the study, and we are grateful to its members for their guidance and encouragement. Donald Trauger chaired the committee composed of Ed Aebischer, Bill Alexander, Darryl Armstrong, Stan Auerback, Deborah Barnes, Waldo Cohn, Charles Coutant, Joanne Gailar, Carolyn Krause, Charles Kuykendall, Ellison Taylor, Michael Wilkinson, Alexander Zucker--all current or retired Laboratory employees. Anne Calhoun and Kim Pepper, also Laboratory staff members, coordinated the committee's work.

Our exploration of historical sources was facilitated by librarians Mary Alexander, Gabrielle Boudreaux, Bob Conrad, Nancy Gray, Diane Griffith, Kendra Jones, Bill Murphy, Debra York; by Bill Cabage, Linda Cabage, Ray Evans, and Lynn Rohm of Public Affairs; by Becky Evans and Lowell Langford of Central Files; and by Carolyn Krause and Jim Pearce of Publications. The authors appreciate their kind assistance.

For making available the resources of the Children's Museum of Oak Ridge, we owe special thanks to Jane Aldersfer, Jim Overholt, and Selma Shapiro. Research assistants Susan Schexnayder, Cathy Shires, and Edythe Quinn provided invaluable insights into the voluminous materials, and administrative assistant Becky Robinson helped keep the information in order once it was collected.

For enlightenment and inspiring ideas, we are indebted to Laura Fermi, Richard Fox, Milton Lietzke, Herbert MacPherson, Herbert Pomerance, Herman Postma, Raymond Stoughton, Chet Thornton, Elaine Trauger, Alvin Trivelpiece, Alvin Weinberg, and a host of Laboratory personnel who took time from their busy schedules for both formal interviews and informal chats that broadened our understanding of the Laboratory's past.

Astrophysicists tell us the space-time continuum and the behavior of light prevent us from seeing a true image of the present. Like it or not, these physicists say, only the past provides a clear portrait of our lives and behavior--a conclusion that historians are more than eager to share. We hope this exploration of Oak Ridge National Laboratory's past will be conducive to a better understanding of its present, serving both as a guidepost for the Laboratory's strengths and a roadmap for its future endeavors.

Leland Johnson
Daniel Schaffer

CHAPTER I

THE EMBATTLED LABORATORY

With broad valleys cut by the Clinch River and framed by the foothills of the Appalachian mountains, Oak Ridge is a pleasant place. Along its highest ridges, a person can gaze at the majestic, cloud-capped Great Smoky Mountains to the east and the stately, tree-covered Cumberland Plateau to the west. Southern Appalachia is a region of unique character with folkways as rich as those of New York City's East Side or Louisiana's Cajun country. Its rugged, yet beautiful, terrain has proved fertile ground for a lifestyle defined by independence and self-determination.

At the time of the Japanese attack on Pearl Harbor in early December 1941, century-old family farms and small crossroads communities such as Scarborough and Wheat occupied the Oak Ridge area. Outsiders thought the region quaint, a throwback to the 19th-century frontier that time and progress had bypassed.

In truth, the area experienced enormous change during the early 20th century. On the upside, it felt the effects of Henry Ford's automobile and shared, to some extent, the comforts afforded by electricity; on the downside, it reeled from the aftershocks of the Great Depression that rocked the economy and exerted additional pressures on the region's fragile natural resources. Located just twenty-five miles from the Tennessee Valley Authority's corporate headquarters at Knoxville and just fifteen miles below TVA's huge Norris Dam on the Clinch River, the area was, in fact, a focal point of one of the nation's boldest experiments in social and economic engineering. The tiny Wheat community, for example, had been selected for a TVA-inspired venture in cooperative agriculture.

Residents of the Oak Ridge area in 1941 did not feel bypassed by history. But the advent of the automobile, the introduction of electricity, the hardships of the Great Depression, and direct participation in an unprecedented government-sponsored social experiment did not prepare them for what was about to happen. In early 1942, the Army Corps of Enginners identified a 59,000-acre swatch of land between Black Oak Ridge to the north and the Clinch River to the south as a federal reservation to serve as one of three sites nationwide for the development of the atomic bomb. Residents received court orders to vacate their ancestral homes within weeks, and thousands of scientists, engineers, and workers swarmed into Oak Ridge to build and operate three huge facilities that would change the history of the region and the world forever.

On the reservation's western edge rose K-25, or the gaseous diffusion plant, a warehouse-like building covering more area than any building ever built. Completed at a cost of $500 million and operated by 12,000 workers, the K-25 plant separated uranium-235, an isotope better suited for achieving a nuclear reaction, from uranium-238. On its northern edge, near the workers' city named Oak Ridge, rose the Y-12 plant where an electromagnetic method was used to separate uranium-235. Built for $427 million, the Y-12 plant employed 26,000 workers. Near the southwest corner of the reservation, about ten miles from Y-12, was the third plant, X-10.

Built between February and November 1943 for $12 million and employing only 1513 people during the war, X-10 was much smaller than K-25 and Y-12. As a pilot plant for the larger plutonium plant built at Hanford, Washington, X-10 used neutrons emitted in the fission of uranium-235 to convert uranium-238 into a new element, plutonium-239. During the war, X-10 was called Clinton Laboratories, named after the nearby county seat of rural Anderson County; in 1948, X-10 was to become the Oak Ridge National Laboratory.

The Laboratory, which celebrates its 50th anniversary in 1993, has evolved from a war-emergency pilot plant operated under the cloak of secrecy, into one of the nation's premier research centers for energy, environment, basic science, and technology. It currently employs about 4500 people including many scientists recognized internationally as experts in their fields. The Laboratory's endeavors range from studies of global warming to energy conservation to superconductivity to tropical rainforest depletion, nuclear medicine, and basic research. Its institutional roots, however, lie with the awesome power released by the atom when its nucleus undergoes fission.

The Laboratory's nuclear roots run deep and nourish much of its research to improve the safety of commercial nuclear power, to identify effective methods of managing nuclear waste, and to achieve practical fusion power. The roots are not only deep, they are broadly international in scope, extending from the banks of the Clinch River to the banks of the Danube River in Budapest, Hungary, from the mountains of East Tennessee to the Rocky Mountains in Colorado, the Ural Mountains in the former Soviet Union, Mount Fuji in Japan, and myriad points between.

Supreme irony marks the Laboratory's history: the institution was born during war and propelled by a sense of urgency that, if Hitler's scientists unleashed atomic power first, Nazi Germany might place the entire world under a fascist fist. Yet, the Laboratory's present scientific excellence could not have been achieved without the camaraderie and sense of collective purpose that propels international science. Created to build a weapon capable of unprecedented destruction, the Laboratory became an institution that nurtures the ability of people to understand and transform their universe for the better. For this reason and more, its history merits the telling.

LABORATORY ROOTS

The history of the Oak Ridge National Laboratory begins in three distinctly different places: the bucolic shoreline of Long Island, New York; the elegant and imposing executive offices of the White House in Washington, DC; and the ivy-covered walls of university laboratories throughout the nation and overseas, especially at the University of Chicago.

At its highest level, the scientific community is international in scope. As fascist dictators seized power in Europe during the 1930s, some of Europe's greatest scientists fled the Continent to join colleagues in Britain and America. Among them were the German Albert Einstein, the Italian Enrico Fermi, and Hungarians Edward Teller, Leo Szilard, John von Neumann, and Eugene Wigner. These brilliant minds joined cooperative international efforts to develop atomic weapons and, later, nuclear energy, significantly influencing twentieth century history in general and the history of Oak Ridge National Laboratory in particular. Eugene Wigner, in fact, has been called the "patron saint" of the Laboratory.

Eugene Wigner, a pioneering chemical engineer and physicist from Budapest, may have been the least known of the immigrant scientists. Completing a chemical engineering degree in Berlin in 1925, Wigner took a job at a Budapest tannery where his father also worked. Physics was his evening and weekend hobby. His friend John von Neumann called his attention to mathematical group theory, and Wigner soon published a series of technical papers that applied symmetry principles to problems of quantum mechanics. After two years at the tannery, he accepted an assistantship in theoretical physics in Berlin at the princely salary of $32 per month.

At Berlin and Gottingen, Wigner established an international reputation as a physicist, and in 1930 Princeton University hired both him and von Neumann, each on a half-time basis. For a few years, the two friends commuted every six months between Berlin and Princeton until the Nazi government terminated their employment. Wigner then went to the University of Wisconsin to work with Gregory Breit. There, he devised a fundamental formula that enabled scientists to understand netron energy's variations when channelled through absorption cross-sections. At Wisconsin, he also discovered a university life that reached beyond academic circles to plain people who grew potatoes and milked cows, and he met scientists who repaired their cars and did home improvements. He later said that at Wisconsin he came to love his adopted country.

Returning to Princeton, he studied solid state physics and supervised graduate work. His first graduate student, Frederick Seitz, later became president of the National Academy of Sciences and of Rockefeller University; his second, John Bardeen, developed the transistor and twice received the Nobel prize for physics.

Rising fascist governments in Europe troubled Wigner deeply. As a youngster, he had seen Hungary's enfeebled monarchy supplanted by brutal communist and then fascist governments. From personal experience, he developed an implacable enmity toward totalitarian regimes. When he learned in early 1939 that two German chemists had discovered nuclear fission in uranium, Wigner recognized that this discovery could lead to both weapons of mass destruction and abundant energy for mass consumption. Fearing Nazi Germany would initiate a crash program to develop atomic weapons, Wigner urged the United States government to support research on nuclear fission. He found an ally in his fellow countryman Leo Szilard, who in Hungary had attended the same schools as Wigner before emigrating to the United States.

Studying nuclear fission with Enrico Fermi at Columbia University in New York City, Szilard needed additional funds to continue his experiments with uranium and graphite. Wigner gladly lent his support to Szilard's efforts. Because other scientists were importuning authorities with their own weapon schemes, Wigner and Szilard found their campaign for nuclear fission research moved so slowly they seemed to be "swimming in syrup."

Thinking that Washington offical s would more likely listen to the famous Albert Einstein, an old acquaintance from Berlin, Wigner and Szilard sought him out in July 1939. Learning he had left Princeton for vacation on Long Island, they motored there, found Einstein's cabin, and explained to him why the United States should initiate fission research before German scientists developed an atomic weapon. As Wigner later recalled:

> Einstein understood it in half a minute. It was really uncanny how he dictated a letter in German with enormous readiness. It is not easy to formulate and phrase things at once in a printable manner. He did. I translated that into English. Szilard and Teller went out, and Einstein signed it. Alexander Sachs took it to Washington. This helped greatly in initiating the uranium project.

In October 1939, President Franklin Roosevelt appointed a committee of prominent scientists and government administrators to manage federally funded scientific research. Wigner, Szilard, and Edward Teller met the committee and requested $6,000 to purchase graphite for fission experiments. They listened to an Army officer on the committee expound at length upon his theory that civilian and troop morale, not experimental weapons, won wars. Szilard later recalled that "suddenly Wigner, the most polite of us, interrupted him. He said in his high-pitched voice that it was very interesting for him to hear this, and if this is correct, perhaps one should take a second look at the budget of the Army, and maybe the budget should be cut." The officer glared in silence at Wigner, and the committee agreed to provide funds for the experiments.

This first $6,000 of federal funding for nuclear energy research launched a vast program that has continued unabated under the successive management of the U.S. Army, Atomic Energy Commission, Energy Research and Development Administration, and Department of Energy.

The initial funds for the uranium and graphite experiments, however, were not released until late 1940. Wigner became increasingly exasperated as the irreplaceable months passed. After the war, he contended that the delay, largely due to bureaucratic footdragging, cost many lives and billions of dollars. American scientists, nevertheless, made vital advances in the interim. At Columbia University, in March 1940, John

Dunning and his colleagues demonstrated that fission occurred more readily in the isotope uranium-235 than in uranium-238, but only one of 140 uranium atoms was the rare 235 isotope. Using cyclotrons at the University of California, in 1940, Edwin McMillan and Philip Abelson discovered the first transuranium element, number 93 on the atomic periodic table. They named it neptunium. A year later, Glenn Seaborg and colleagues discovered element 94, naming it plutonium (in the planetary sequence Uranus, Neptune, Pluto), and demonstrated its fissionability. Two doors to atomic weapons and energy thus were opened for future exploration: uranium-235 could be separated from uranium-238 for weapons production, and uranium-238 could be bombarded with neutrons, created by the fission of uranium-235 in a nuclear reactor, to produce plutonium for weapons.

METALLURGICAL LABORATORY

The day after the Japanese attacked Pearl Harbor, Arthur Compton, a Nobel Laureate at the University of Chicago, contacted Eugene Wigner to discuss the possibility of consolidating plutonium research efforts, taking place across the nation, in Chicago. At meetings in January 1942, Compton brought together scientists experimenting with nuclear chain reactions at Princeton and Columbia with those investigating plutonium chemistry at the University of California and elsewhere to outline the plutonium project's objectives. Compton's schedule called for determining the feasibility of a nuclear chain reaction by July 1942, achieving the first self-sustaining chain reaction by January 1943, extracting the first plutonium from irradiated uranium by January 1944, and producing the first atomic bomb by January 1945. In the end, all these deadlines were met except the last, which occurred six months later than planned.

To accomplish these objectives, Compton formed a laboratory, called the "Metallurgical Laboratory" as cover, at the University of Chicago and brought scientists from the East and West coasts to this central location to (1) develop chain-reacting piles for plutonium production, (2) devise methods for extracting plutonium from irradiated uranium, and (3) design a weapon. Remaining in charge of the overall project, Compton selected Richard Doan as Metallurgical Laboratory Director. An Indiana native, Doan had earned a physics degree from the University of Chicago in 1926 and had been a researcher for Western Electric and Phillips Petroleum before the war.

Compton also placed Glenn Seaborg in charge of the research on plutonium chemistry, striving for methods to separate plutonium from irradiated uranium in quantities sufficient for bomb production. To coordinate the theoretical and experimental phases of research associated with a chain reaction, Compton chose Wigner, Fermi, and Samuel Allison. Fermi continued his experiments with ever-larger piles of uranium and graphite, while Samuel Allison directed a cyclotron group, including Canadian

Arthur Snell, which assessed nuclear activities in uranium and graphite piles.

Eugene Wigner headed the theoretical physics group crowded into the garrets of Eckart Hall on the University of Chicago campus. His "brain trust" of twenty scientists studied the arrangement, or lattice, of uranium and control materials for achieving a chain reaction and planned the design of nuclear reactors. Among Wigner's group were Gale Young, Kay Way, and Alvin Weinberg, all of whom later moved to Oak Ridge.

Having a chemical engineering background, Wigner also advised Glenn Seaborg and his staff of University of California chemists who were seeking to separate minuscule traces of plutonium from uranium irradiated in cyclotrons. This task was particularly challenging because to that point no one had isolated even a visible speck of plutonium. By September 1942, the team had obtained a few micrograms for experimentation, but they needed much more for additional analysis.

In 1942, Compton brought Martin Whitaker, a North Carolinian who chaired New York University's physics department, to Chicago to help Fermi and Walter Zinn build subcritical uranium and graphite piles. He later put Whitaker in charge of a laboratory under construction in the Argonne forest preserve on Chicago's west side. It was here that Compton initially planned to bring the first nuclear pile to critical mass. A strike by construction workers, however, prevented the laboratory's timely completion. As a result, Compton and Fermi decided to build a graphite pile housed in a squash court under the stands of the University of Chicago's stadium.

Leo Szilard and later Norman Hilberry were placed in charge of supplying materials for the pile experiments. They obtained impurity-free graphite from Herbert McPherson of National Carbon Company in Cleveland, Ohio, and the purest uranium metal from Frank Spedding's research team at Ames, Iowa. Fermi and his colleagues put these materials in a series of subcritical uranium and graphite piles built in what was to become the world's most famous squash court. Fermi called them "piles" because, as the name implies, they were stacks or piles of graphite blocks with lumps of uranium interspersed between them in specific lattice arrangements. Uranium formed the "core," or source of neutrons, and graphite served as a "moderator," slowing the neutrons to facilitate nuclear fission. In truth, the piles were small, subcritical nuclear reactors cooled by air, but the name "reactor" did not supplant "pile" until 1952. Fermi gradually built larger subcritical piles, carefully measuring and recording neutron activity within them, edging toward the point where the pile would reach "critical mass" and the reaction would be self-sustaining.

On December 2, 1942, Fermi, Whitaker, and Zinn 'piled' tons of graphite and uranium on the squash court to demonstrate a controlled nuclear reaction for visiting dignitaries standing on a balcony. Controlling the reaction with a rod coated with cadmium, a neutron-absorbing material, Fermi directed the phased withdrawal of the rod, carefully measuring the increased neutron flux within the pile at each pass. The pile went "critical," achieving self-sustaining status at 3:20 p.m., an event later hailed as the dawn of "the Atomic Age." Having no shield to prevent a release of radiation, Fermi briefly operated this Chicago Pile 1, disassembled it, and in 1943 rebuilt it with concrete, radiation-protecting shielding as Chicago Pile 2 at the Argonne laboratory.

Richard Fox, who rigged the control rod mechanism for Fermi's pile, stood behind Fermi worrying throughout the first critical experiment. "The manual speed control was nothing more elaborate than a variable resistor," Fox recalled, "with a piece of cotton clothes line over a pulley and two lead weights to make it 'fail safe' and return to its zero position when released." After the experiment succeeded and his concern about the clothes line's slipping off the pulley proved unfounded, Fox recalled his elation: "It was as though we had discovered fire!"

After the dignitaries departed, Eugene Wigner brought out a bottle of Italian Chianti in honor of Fermi's achievement and shared toasts with the workers. He had carried the bottle from Princeton and later claimed it had taken more foresight to anticipate that Chianti would become a rare wine than that Fermi's chain reaction would succeed. After emptying the bottle in celebration, those present signed it. Among the signatories were Richard Fox and Ernest Wollan, who had monitored and recorded the radiation emitted by the reaction. Both left Chicago for Oak Ridge in 1943 where Wollan conducted neutron diffraction experiments and Fox joined the Instrumentation and Controls Division, where he worked for a half century.

Producing sufficient plutonium for weapons would require the construction of large reactors operating at high power levels and releasing great heat and radiation. Metallurgical Laboratory engineers Thomas Moore and Miles Leverett, both recruited from the Humble Oil Company, began an intensive investigation of potentially larger reactor designs. Scaling up Fermi's pile would not do, because extracting plutonium from the uranium would require tearing the pile apart each time and then reassembling it--a risky, time-consuming exercise. Moore and Leverett developed a new design that used helium gas under pressure as the coolant to remove heat from the pile during a nuclear reaction. To extract the uranium without disassembling the graphite moderator, they designed holes or channels that extended through the graphite to allow the insertion of uranium rods. The rods could then be removed after they had been irradiated.

Scientists agreed that thick shells of concrete could contain the radiation from reactors, but they disagreed about methods for removing the heat. Enrico Fermi wanted an air-cooled reactor, with fans forcing air through channels alongside the uranium rods. Moore and Leverett preferred using helium gas under pressure. Leo Szilard favored a liquid bismuth metal coolant, similar to the system he and Einstein had patented for refrigerators. And Wigner preferred plain river water, with uranium rods encased in aluminum to protect against water corrosion. Wigner's water cooling plan eventually was adopted for use in the large production reactors, but not before the decision to build Fermi's air-cooled graphite and uranium pilot reactor at Oak Ridge had been made.

The proposed pilot reactor would test control and operations procedures and provide the larger quantities of plutonium needed for study by the project's chemists. In mid-1942, Glenn Seaborg's group had used a lanthanum fluoride carrier process to separate micrograms of plutonium from uranium irradiated in cyclotrons; they now sought a means to achieve the separation on an industrial scale. In addition, Isadore Perlman, Charles Coryell, Milton Burton, George Boyd, and James Franck headed teams investigating the chemical novelties of plutonium, radiation, and fission products created during nuclear reactions. Of the various methods being investigated for separating plutonium, Seaborg and DuPont chemist Charles Cooper settled on two: a small pilot plant using the lanthanum fluoride carrier was built on the Chicago campus and another pilot plant using a bismuth phosphate carrier was planned for Oak Ridge. In both cases, the separation would have to be conducted by remote control in "hot cells" encased in thick concrete to protect the chemists from radiation.

TO THE HILLS

As the Metallurgical Laboratory's research continued, studies of potential sites for the planned industrial-scale uranium separation plants and pilot plutonium production and separation facilities began. An isolated inland site with plenty of water and abundant electric power was desired. At the recommendation of the War Production Board, Compton's chief of engineering, Thomas Moore, and two consulting engineers visited East Tennessee in April 1942. They found a desirable site bordering the Clinch River between the small towns of Clinton and Kingston that was served by two railroads and Tennessee Valley Authority electric power. Arthur Compton then inspected the site, approved it, and visited David Lilienthal, chairman of the Tennessee Valley Authority, to describe the unfolding plans to purchase the land.

Lilienthal was dismayed by news that land near Clinton would be taken. He objected that the site included land selected for an agricultural improvement program and proposed instead that Compton choose a site in western Kentucky near Paducah.
Compton refused to consider Lilienthal's proposal and advised him that the land in East Tennessee would be taken through court action for immediate use. He urged Lilienthal not to question his judgement or inquire into the reasons for the purchase. "It was a bad precedent," Lilienthal later complained. "That particular site was not essential; another involving far less disruption in people's lives would have served as well, but arbitrary

bureaucracy, made doubly powerful by military secrecy, had its way."

In June 1942, President Roosevelt assigned to the Army the management of uranium and plutonium plant construction and nuclear weapons production. High-ranking Army officials, in turn, delegated this duty to Colonel James Marshall, commander of a Manhattan Engineer District headquartered initially in New York City and later relocated to Oak Ridge. Because Fermi had not yet achieved a self-sustaining chain reaction, Marshall and Army authorities postponed their efforts to acquire the land. The delay disturbed some scientists anxious not to lose ground to the Germans. It also perturbed the hard-driving deputy chief of the U.S. Army Corps of Engineers, General Leslie Groves.

Given command of the Manhattan Project in September 1942, Groves ordered the immediate purchase of the reservation, first given the code name Kingston Demolition Range after the town south of the reservation and later renamed Clinton Engineer Works after the town to the north. The Army sent an affable Kentuckian, Fred Morgan, to open a real estate office near the site and purchase the land through court condemnation, thereby securing clear title for its immediate use. About 1000 pioneer families on the reservation were paid for their land and forced to relocate. Existing structures were demolished or converted to other uses.

To speed production of weapons materials, Groves selected experienced industrial contractors to build and operate the plants. In January 1943, he persuaded the DuPont Company to initiate construction of the pilot facilities at X-10 and also of the full-scale reactors to be built later in Hanford, Washington. Involved in too many military projects and reluctant to undertake the work at X-10, DuPont executives were persuaded to accept Grove's request partly through appeals to their patriotism. The contract stipulated that DuPont would withdraw from the job at war's end, accept no work-related patents, and receive no payment other than their costs plus a $1 profit. After the war, Groves reported with amusement that government auditors allowed DuPont a profit of only sixty-six cents because the company had finished its job ahead of schedule.

Groves called on the University of Chicago to operate the pilot plutonium plant planned at X-10. Scientists at the Metallurgical Laboratory in Chicago expressed initial dissatisfaction with this proposal. Eugene Wigner and others had wanted to design and construct the plants, and they were not interested in operating them after DuPont had been given the jobs they had sought. Also, university scientists and administrators preferred building the pilot plant in the Argonne forest convenient to Chicago; the prospect of operating industrial facilities 500 miles from their campus in the remote hills of Tennessee did not elicit much enthusiasm. Again, Groves and the Army used appeals to patriotism to help persuade the university to accept the challenge. The compromise called for Chicago to supply the managers and scientists needed for the operations and for DuPont to mobilize construction and support personnel.

X-10 CONSTRUCTION

On February 2, 1943, DuPont started clearing the X-10 site, installing utility systems, and building the first temporary buildings, mostly wooden barracks. In March, construction of six "hot cells" for plutonium separation began. The cells had five-foot-thick concrete walls with removable slab tops for equipment replacement. The cell nearest the nuclear reactor housed a tank for dissolving uranium brought from the reactor through an underground canal; four other cells housed equipment for successive chemical treatments--precipitation, oxidation, reduction--of the uranium; the sixth cell stored contaminated equipment removed from the other cells. A frame structure, abutting the cell walls, housed the remote operating gallery and offices.

Other structures rising at X-10 housed chemistry, physics, and health physics laboratories, machine and instrument shops, warehouses, and administration buildings. Because construction of the Y-12 and K-25 plants on the reservation also began in 1943, DuPont had difficulty finding enough workers. It remedied the shortage by dispatching recruiters throughout the region.

Including the smallest structures, about 150 buildings were completed that summer by 3000 construction workers, at an initial cost of $12 million. The construction materials used included 30,000 cubic yards of concrete, 4 million board feet of lumber, 4500 gallons of paint, and 1716 kegs of nails. Buildings went up rapidly, but needs so outran accommodations that a workers' cafeteria operated in a striped circus tent and an old schoolhouse served as office space and a dormitory.

Foundation excavations for the graphite reactor began in late April 1943; the reactor's thick concrete front face was in place by June and the side and rear walls were constructed in July. The National Carbon Company delivered graphite of the required purity to X-10, where DuPont built a fabrication shop to machine graphite blocks to the desired dimensions. In September, a crew stacked the first of seventy-three layers of graphite blocks within the concrete shield to form a twenty-four-foot cube, and at month's end installed steel trusses to support the heavy concrete lid capping the reactor. Under government contract, the Aluminum Company of America began encasing 60,000 uranium slugs in aluminum for the reactor. Mounted in a building near the reactor, two of the world's largest fans sucked outside air through the reactor and into a filter house, then up a stack. The stack and the black building that housed the reactor (called the "black barn") were prominent features everyone noticed when arriving at X-10 during the war.

FILTER HOUSE in initial design ?

Because Wigner had changed the cooling system design for the larger reactors built at Hanford, Washington, from helium to water, the air-cooled X-10 reactor was not truly a pilot plant for Hanford's water-cooled reactors. Instead, DuPont officials viewed the hot cells of the separations building adjacent to the X-10 reactor as a pilot plant for similar facilities to be built at Hanford, and they considered development of chemical separations processes the most challenging mission at X-10.

The plutonium separation system challenged chemical engineers to design, fabricate, and test equipment for remotely transferring and evaporating liquids, dissolving and separating solids, and handling toxic gases. Instrumentation for remote measurement of volumes, densities, and temperatures in a lethal environment was needed. Techniques to separate microscopic amounts of solids in pure form from liquid volumes thousands of times larger had to be perfected. The unknown effects of intense radiation on the solvents had to be identified and handled. Disposal of contaminated equipment and unprecedented volumes of radioactive wastes had to be addressed. These were a few of the challenges facing DuPont and Clinton Laboratories personnel as work progressed at X-10 during the autumn of 1943.

The organization of Clinton Laboratories was in constant flux during the war. Scientists and technicians moved from Chicago to Oak Ridge to Hanford and Los Alamos as if they were in a revolving door. Many members of the original staff came from Chicago, and the DuPont Company brought its personnel to Oak Ridge for training, then moved them to Hanford. Most DuPont personnel came to X-10 from ordnance plants the company had constructed before 1943. After construction workers had departed X-10 for other work, wartime employment at Clinton Laboratories leveled off in 1944 at 1513 scientists, technicians, and operating personnel, including 113 soldiers from the Army's Special Engineering Detachment assigned to the Manhattan Project.

Organization of the Laboratory proceeded in 1943, with Martin Whitaker as its director and Richard Doan as its associate director for research. Reporting directly to Whitaker were research manager Doan, Simeon Cantril (and later John Wirth) of the Health Division and Plant Manager S.W. Pratt, who brought many DuPont personnel to Oak Ridge. When its organization took shape, Clinton Laboratories had eight units: chemistry, physics, technical, health, production, works engineering, services, and accounting.

REACTOR GOES CRITICAL

By Halloween in 1943, when DuPont had completed the reactor's final technical tests, Whitaker brought Compton and Fermi from Chicago to witness its first operation. Three days later, workers began to insert thousands of uranium slugs into the reactor. The sequence involved loading a ton or two, withdrawing control rods to measure the increase in neutron flux, re-inserting the rods into the pile, loading another batch of uranium, then stopping again to assess activity, each time attempting to estimate when the reactor would achieve a self-sustaining chain reaction. A second shift continued this tedious procedure into the night, with Henry Newsom and George Weil plotting the flux curve. Weil had manipulated the control rod when Fermi brought Chicago Pile 1 to criticality the previous December, and he had come from Chicago to help achieve the same result in Oak Ridge.

The day shift loaded nearly ten tons, and the night shift set out to beat this record, working at both ends of the scaffold elevator at the reactor's face, under the supervision of Kent Wyatt. In the middle of the night, Newsom and Weil, in the plotting room, recognized that one more batch of slugs would bring the reactor to the critical point, and they stopped the loading. Before dawn on November 4, Louis Slotin drove into Oak 1943
Ridge to awaken the two Nobel laureates, Compton and Fermi, known by the aliases Holley and Farmer in Oak Ridge. In the dark, they raced down Bethel Valley Road to witness the reactor going critical at five that morning. Scientists aware that the world's first powerful nuclear reactor had gone critical that morning were thrilled. John Gillette, a DuPont engineer on the graveyard shift that had loaded the last twenty tons of uranium slugs, was too pooped to care.

Arthur Rupp of the Engineering Division had been dubious of Wigner's theoretical calculations of the amount of heat energy that uranium would emit during fission. To test the computations, he and his colleagues calibrated the airflow through the reactor and installed temperature, humidity, and barometric instruments. They then compared the exact fissioning rate in the reactor with the amount of heat released. When the experimental value proved nearly the same as the theoretical prediction, Rupp's skepticism ended. "I knew then," he said, "the atomic bomb was going to work!"

As Wigner and Alvin Weinberg at Chicago had predicted during the design phase, the reactor had gone critical when about half its 1248 channels were loaded. Initially called the X-10 or Clinton Pile, it became known as the reliable graphite reactor, so well designed that it worked with few operational difficulties throughout twenty years of service. Near the end of November 1943, it discharged the first uranium slugs for chemical separation. By year's end, the chemists had successfully extracted 1.54 milligrams of plutonium from the slugs and dispatched them to Chicago, apparently by secret courier, in a container resembling a fountain pen. Blocking empty channels in the graphite (to concentrate the cooling air) allowed an increase in the reactor's thermal power to 1,800 kilowatts in early 1944; subsequent air flow modification, plus the installation of larger fans for cooling, permitted its operation at more than 4,000 kilowatts, four times the original design capacity, with corresponding increases in plutonium production.

PLUTONIUM PRODUCTION

In February 1944, the first plutonium shipment went to Los Alamos. By spring, the chemists had improved the bismuth phosphate separation process to the point that ninety percent of the plutonium in the slugs was recovered. By early 1945, when

∴ only separated Pu ~ 1 1/2 yr

plutonium separation ceased at X-10, the graphite reactor and separations plant had produced a total of 326.4 grams of plutonium, a substantial contribution to nuclear research and ultimately to weapons development.

In early 1945, Robert Oppenheimer urgently requested Clinton Laboratories to supply Los Alamos with large quantities of pure radioactive lanthanum, called "RaLa," which is the decay product of radioactive barium-140. Clinton's chemists separated the first quantity of this isotope from the reactor's fission products in glass equipment in the chemistry laboratory. To attain larger and safer production levels, Martin Whitaker assigned Miles Leverett the job of designing, constructing, and operating a barium-140 production facility. With support from the Chemistry Division, Leverett and his chemical engineers met the schedule and Oppenheimer's requirements. "I believe," Leverett later speculated, "that this was the first production of a radioisotope on a large scale."

To assist with the design of Hanford's plutonium production reactors, many experiments were performed at the graphite reactor during 1944. One test involved laminated steel and masonite radiation shields designed for Hanford. The shield samples were set in an opening at the graphite reactor to study the interactions between the samples and radiation. Brass, neoprene, bakelite, rubber, and ordinary construction materials to be used at Hanford also were exposed to radiation in the graphite reactor for performance analysis. Because the Hanford reactors were to be water-cooled, tubes were installed in the graphite reactor to circulate water and observe its cooling and corrosive effects.

The conventional relationship between pilot plant and production plant existed between the Clinton Laboratories' hot cells and similar concrete structures built at Hanford. The Clinton experience indicated the bismuth phosphate carrier process was not entirely suitable for the concentration process, but Seaborg's other process, using lanthanum fluoride, worked well. This experience was incorporated into Hanford's concentration facilities. So was the experience of hundreds of personnel trained at Clinton Laboratories.

John Wheeler worried that unwanted isotopes capable of stopping chain reactions would be found in the irradiated uranium. Like the boron and cadmium used in reactor control rods, the isotopes would have a large neutron capture cross-section, meaning they would absorb enough neutrons to kill a nuclear chain reaction. This problem occurred at the first Hanford reactor during its trial run, a nasty surprise to Fermi and all concerned. After the chain reaction became self-sustaining, the reactor stalled. After a few hours, the reactor, for unexplained reasons, started again. Fermi and Wheeler suspected that the isotope xenon-135, which decays in about the same time that the reactor had shut down, was the culprit.

Urgent, around-the-clock efforts to measure the neutron-absorption cross section of xenon-135 began at the Argonne and Clinton laboratories. Scientists worked forty hours at a stretch to separate xenon-135 from its parent iodine, place samples in the graphite reactor, and obtain rough estimates of its ability to capture neutrons, an ability measured in "barns" (from the folk idiom "big as the broad side of a barn").

They measured xenon-135 at four million barns; that is, tiny amounts of xenon could shut down large reactors, which would start again after the xenon decayed. Later, George Parker's team separated xenon samples produced at the graphite reactor, and Seymour Bernstein and associates precisely measured xenon's cross-section and related characteristics.

Scientists blamed Clinton Laboratories for not detecting xenon's effects during earlier graphite reactor operations. A decline of reactivity resulting from xenon poisoning had occurred in the graphite reactor, but the reactor's conservative design had overcome the poisoning effects. The reactor did not shut down, and the staff had not noticed its decline in reactivity. Fortunately, at Hanford the DuPont engineers had designed reactors larger than necessary. This overdesign allowed the insertion of sufficient uranium fuel to overcome xenon's poisoning effects and continue production of the plutonium later used in the "Trinity" test in July 1945 and in the bomb that devastated Nagasaki in August.

BATTLE OF THE LABORATORIES

Announcing the bombing of Hiroshima, President Harry Truman mentioned the weapons facilities built at Oak Ridge, Hanford, and Los Alamos, commenting: "The battle of the laboratories held fateful risks for us as well as the battles of the air, land and sea, and we have now won the battle of the laboratories as we have won the other battles."

This news came as a surprise even to some employees at Clinton Laboratories. Before he heard the President's announcement, reactor operator Willie Schuiten did not believe co-workers who told him the reactor's work was tied to a new weapon. He later commented, "The people in charge really did a good job of keeping the project a secret." Many Oak Ridge scientists, however, knew or surmised the purposes of the project. News of the bomb's success elated them, especially if they had relatives serving in the armed forces in the Pacific. One physicist commented that "we had helped to do a bold and difficult job, and had stopped a war in its tracks." He added, "That was enough for the moment. Second thoughts came later."

A few days later came Nagasaki, Japan's surrender, and the end of World War II. Staff members drifted about Clinton Laboratories, gathering and talking, seemingly bereft of energy. "Everyone felt," admitted one scientist, "a sense of disorientation, of slackness, of loss of direction."

The war's end had come while Clinton Laboratories was in the throes of a management change. In July 1945, one month before the first atomic bomb was dropped, the University of Chicago withdrew as the contract operator, and the Army selected Monsanto Chemical Company as the new operator. This major change, combined with the fact that many scientists planned to return to the universities and their prewar research, raised a fundamental question: "What is to become of the Lab?"

LIVING WITH PEACE

Winning the war left the staff of Clinton Laboratories with both a pride of accomplishment and a sense of anxiety. Their prime task of producing and separating plutonium for use in an atomic bomb had been accomplished on schedule. But with this task successfully completed, the future looked uncertain. Could the Laboratories be as useful and productive in peace as it had been in war? Would its scientists be content to remain in the hills of East Tennessee, or would they return to more cosmopolitan settings in Chicago, New York, and California? Would the federal government be willing to invest as much money in the peaceful uses of nuclear energy as it had in weapons production?

Although the Laboratories had emerged from the shades of war, shadows still darkened its future. Impressed by the bucolic atmosphere of Clinton Laboratories and its impressive record of accomplishment during the war, however, Eugene Wigner thought it did indeed have a future. In late 1944, he drew up a plan for an expanded postwar Laboratory for nuclear research with perhaps 3500 personnel and an associated school of reactor technology.

Furthermore, he hoped he and his theoretical group in Chicago would be transferred as a unit to Oak Ridge. When that was not done, he persuaded some of his staff in Chicago to move south, starting in May 1945 with Alvin Weinberg. Wigner followed in 1946, marking the opening of a volatile era in the Laboratories' history. Like the rest of America and the world, the Laboratory, whose energies and resources had been focused exclusively on war, would have to learn to live with peace.

CHAPTER II

A HIGH-FLUX LABORATORY

High-flux conditions prevailed at Clinton Laboratories after the war, when surprising decisions affecting its future were made in St. Louis, Chicago, and Washington, D.C. At the federal level, management of the national laboratories shifted from General Leslie Groves and the Army Corps of Engineers Manhattan District to David Lilienthal and the newly created civilian Atomic Energy Commission (AEC). In Oak Ridge, Monsanto Chemical Company, the industrial operator for Clinton Laboratories, abandoned its contract, and the University of Chicago, the proposed academic operator, failed to assemble a management team, resulting in the selection of a new industrial contractor, the Union Carbide Company. Clinton Laboratories became Clinton National Laboratory in 1947 and Oak Ridge National Laboratory in 1948. One surprise followed another during the postwar turmoil.

Despite the management tumult, solid accomplishments in science and technology were achieved after the war. Under the leadership of Eugene Wigner, Clinton Laboratories designed a high-flux materials testing reactor, the precursor of all modern light water reactors, and experimented with the Daniels Pile, a forerunner of high-temperature gas-cooled reactors. The first of thousands of radioisotope shipments left the graphite reactor in 1946, initiating a program of immense value to medical, biological, and industrial sciences. New organizational units to pursue fundamental biological, metallurgical, and health physics sciences were formed, and several unexpected and "amusing" scientific accomplishments were recorded at the Laboratories before the departures of Wigner and Monsanto.

Surprising management fluctuations proved a source of anxiety and despair among Laboratory staff during the 1947 Christmas season, but as they started the new year in 1948 these crucial management decisions assured the staff of the survival of X-10 as a national laboratory, with a much broader mandate for fundamental science than it had during the war. Unlike the two other original national laboratories, Argonne and Brookhaven, built afresh during 1948 on the outskirts of Chicago and New York City respectively, the Oak Ridge National Laboratory was to have a distinct semi-industrial character in the midst of rural Appalachia.

MONSANTO'S MANAGEMENT

The remote Appalachian location of Clinton Laboratories, along with unpaved streets and spartan living conditions, presented an easy target for wags. Metallurgical Laboratory personnel in Chicago called X-10 "Down Under," while DuPont personnel labeled it the "Gopher Training School." During the war, security concerns required referring to it in code as X-10, but in the postwar years the practice continued among personnel of Monsanto Chemical Company, the new operating contractor. Even in official telegrams, Monsanto's staff referred to Oak Ridge as

"Dogpatch," taking their cue from a popular comic strip lampooning "hillbilly" Appalachian life. Such ill-concealed scorn did not augur well for the postwar Monsanto administration.

As a chemical company, the choice of Monsanto as contract operator of Clinton Laboratories seemed logical because of the Laboratories' focus on chemistry and chemical technology; Monsanto was also interested in becoming a key player in nuclear reactor development. Charles Thomas, Monsanto vice president, was the driving force behind the company's entry into nucleonics. A native of Kentucky, Thomas earned chemistry degrees from Transylvania University in Lexington, Kentucky, and joined General Motors at Dayton, Ohio, in 1923, where he gained fame for developing ethyl gasoline to reduce engine knock. He formed an independent laboratory at Dayton, developing a synthetic rubber, and Monsanto purchased the laboratory in 1936, making it the company's central research laboratory.

The company appointed Thomas laboratory director and assigned him the task of spearheading research and development of styrene plastics. In 1943, General Groves gave Thomas responsibility for the purification of polonium and fabrication of nuclear triggers at the Dayton laboratory. When Thomas also agreed to supervise the operation of Clinton Laboratories in 1945, he merged both Dayton and Clinton into a single project and appointed himself project director, although he kept his main office at Monsanto headquarters in St. Louis.

When Whitaker and Doan left Oak Ridge, Thomas decided to establish a dual directorship at the Laboratories with both directors reporting to him. For executive director in charge of general administration and operations, he selected James Lum, who had joined Monsanto in 1933 and assisted Thomas in managing the Dayton laboratory. As Lum's assistant, he brought in Prescott Sandidge, who had managed Monsanto phosphate and munitions plants in the South.

Transferring sixty personnel to the Laboratories from other Monsanto plants, Thomas reorganized the Laboratories' administration. Among the new administrators were Robert Thumser as plant manager, Hart Fisher as shop and instrument superintendent, Clarence Koenig as chief accountant, and Harold Bishop as superintendent of support services. Because many scientists returned to universities at the end of the war, Thomas and the Clinton staff also had to recruit replacements. Among the new staff members, for example, were Walter Jordan, P.R. Bell, and Jack Buck who came from the radar laboratory that had closed at the Massachusetts Institute of Technology. The Laboratories' staff reached a high of 2141 in 1947 under Monsanto's management, making facilities expansion imperative. A moratorium on building construction during 1946 and 1947, while the Laboratories' future was debated in Washington, caused personnel and equipment to be moved into empty buildings at the Y-12 plant, which had been closed at the end of 1945 because K-25's gaseous diffusion process had proven more economical than Y-12's electromagnetic separation process.

Expecting to build the nation's first peacetime research reactor and its first electric power-generating reactor, Thomas courted Eugene Wigner, bringing him from Princeton to Oak Ridge several times during late 1945 to conduct seminars and consult on reactor designs. In early 1946, he lured Wigner into a year's leave from Princeton to become the Laboratories' research and development director by promising to relieve him of administrative duties, which Thomas assigned to James Lum. Wigner also acquired an assistant for the administration of research and development. Edgar Murphy, a scientist who had served as Army major during the war in the Manhattan District office, became coordinator for research administration.

When his Princeton colleagues asked Wigner why he was going to Dogpatch, he told them that, as one of the three major nuclear research laboratories in the nation, Clinton Laboratories would become important "in the life of the whole nation." As its research director, he intended to focus on science education by (1) developing research reactors suitable for use at universities, (2) establishing nuclear science training under his former graduate student Frederick Seitz, and (3) coordinating scientific research with universities throughout the South. "Only too much have both Chicago and Oak Ridge lived in the past on fundamental knowledge that has been acquired either before the war or at one of the other government research centers," Wigner observed. He concluded that "as these wells begin to run dry, this situation becomes increasingly unhealthy and we must try our best to contribute to the foundations of our knowledge."

Early in his tenure, Wigner outlined his weekly routine to the staff of Clinton Laboratories. On Mondays, he would remain in his office with an open door to hear their advice and grievances. On "Holy" Tuesdays, he would vanish, pursuing his own research to "keep my knowledge alive." Although he avoided committee meetings to the extent possible, the remainder of the week he would attend to duties, circulating through the Laboratories to discuss scientific and administrative problems with staff. "We'll have long arguments just as you are having them now with each other," he warned, "and I fully expect to be wrong in most of them--that is from Wednesday to Friday."

HIGH-FLUX DESIGNS

When Wigner arrived as research director, Clinton Laboratories was embarking on the design of two new reactor types: a high neutron flux reactor useful for testing materials, and the Daniels Pile for demonstrating nuclear energy's value for electricity production.

Wigner devoted most of his attention to the high-flux reactor, subsequently renamed the materials testing reactor. Its chief function was to provide intense neutron bombardment for testing materials to be used in future reactors. It was a reactor designer's reactor and provided the most intense neutron source ever built.

Initial designs called for use of enriched uranium fuel with heavy water in the interior lattice serving as the moderator and the exterior cooled by ordinary (light) water. Wigner and Alvin Weinberg, appointed by Wigner to be Lothar Nordheim's successor as chief of physics, concluded that heavy water dilution of the fuel could severely reduce the neutron flux. Squeezing heavy water out of the design, they selected ordinary water as both moderator and coolant. Instead of uranium rods canned in aluminum as in the graphite reactor, the fuel element or core would be uranium sandwiched between aluminum cladding or plates. To assure a high neutron flux for research, the plates were surrounded by a reflector made of beryllium. In time, this design served as the prototype for many university research reactors and, in a sense, for all light water reactors that later propelled naval craft and generated commercial nuclear power.

Miles Leverett and Marvin Mann headed a team of scientists and engineers undertaking the materials testing reactor design at Oak Ridge. About sixty personnel over nearly six years became involved in the design, making it difficult to identify contributions of individual team members. Wigner's best-known contribution was the curved design of the aluminum fuel plates in the reactor core. These plates were placed parallel to one another with narrow spaces between for the cooling water; the reactor's power was largely set by how much water flowed past the fuel plates. Concern arose that intense heat might warp the plates, bringing them in contact and restricting coolant flow. After pondering this potential problem, Wigner directed that the plates be warped, or curved, in advance to improve their structural resistance to stress; because the warped plates could bow only in one direction, they would not constrict water flow.

Monsanto's principal concern was the Daniels Pile, named for Farrington Daniels who at the Chicago Metallurgical Laboratory in 1944 had designed a reactor with a bed of enriched uranium pebbles moderated by beryllium oxide and cooled by helium gas. Some called it the pebble-bed reactor. In May 1946, the Manhattan District directed Monsanto to proceed with the design, leading to the construction of an experimental Daniels Pile to demonstrate electric power generation. To accomplish this task, Monsanto brought Daniels from the University of Wisconsin as a consultant. The company also recruited engineers from industry and brought them to Clinton Laboratories, where they formed a Power Pile Division headed by Rogers McCullough. This division identified materials suitable for high-temperature reactors and developed pressure vessels and pumps, piping, and seals for high-pressure coolants; it also studied heat exchanger designs. This high-temperature, gas-cooled reactor type has engaged scientists at Oak Ridge throughout most of the Laboratory's history.

HIGH-TEMP GAS COOLED

Recruited largely from outside Clinton Laboratories, however, the Power Pile Division never fully integrated into the organization. The project, moreover, encountered numerous design problems. Critics of the Daniels Pile contended it would never become a practical power-generating reactor and building a demonstration project wasted time and resources. After all, Logan Emlet and operators of the graphite reactor had demonstrated power production simply with a toy steam engine and generator using heat from the graphite reactor. High-level support for the Daniels Pile waned by 1948. It was never constructed, and Daniels, as a professor at the University of Wisconsin, gained renown as a national expert on solar not nuclear energy.

ATOMS FOR HEALTH

Distribution of the radioisotopes produced at the graphite reactor for biological and industrial research proved to be the most publicized activity at Clinton Laboratories in the postwar years. After Waldo Cohn published a radioisotope catalogue listing what he and his group could prepare and ship in the June 1946 issue of <u>Science</u>, orders began arriving. On August 2, 1946, Wigner stood in front of the graphite reactor to hand the first peacetime product of atomic energy, a small quantity of carbon-14, to an official of a cancer research hospital in St. Louis, home of Monsanto Chemical Company. Nearly fifty types of radioisotopes soon were regularly shipped from Clinton Laboratories. In 1947, to handle their production and distribution, Logan Emlet of Operations established an Isotopes Section headed by Arthur Rupp; as the program grew, it later became an Isotopes Division headed by John Gillette, James Cox, and others.

One of the earliest cases of technology transfer from the Laboratories came as a spinoff of the radioisotopes program. Abbott Laboratories located its original radiopharmaceutical production plant in Oak Ridge near the source of radioisotopes at the Laboratory. The plant moved to Chicago in the 1960s when the Laboratory ceased commercial production of most radioisotopes.

HIGH-FLUX ORGANIZATION

Like most new managers, Wigner sought to sharpen the Laboratories' mission and improve performance through reorganization. He made both minor changes, such as the appointment of Edward Shapiro as chief of technical libraries, and major changes, involving the formation and staffing of new divisions. Thinking solid state physics a key to reactor design, Wigner established a small group for solid state studies in the Physics Division under Sidney Siegel and Douglas Billington; he formed a new Research Division to investigate the response of metals to radiation; and he persuaded Monsanto executives to consolidate and augment staffing of the machine shops that supported the research projects.

During the war, small machine shops scattered among several divisions had provided the tooling, jewelry finishing, and precision machine work required for scientific experimentation.

In 1946, Wigner urged that these shops be merged into groupings comprising at least 200 craftsmen. After some resistance to the suggestion, Executive Director James Lum established the central research shops in 1947 and imported Paul Kofmehl, a Swiss craftsman, as superintendent with Earl Longendorfer as his assistant.

Skilled craftsmen, who machined the hardware for the reactors and other projects, gathered in the research shops. They acquired apprentices in the ancient tradition of the crafts and supplied scientists and engineers with the unique equipment and tools they required. As the workload expanded, the research shops evolved into central machine shops and eventually became a Fabrication Department in the Plant and Equipment Division under the supervision of Robert Farnham. The shops even included an old-fashioned Tennessee blacksmith, Miller Lamb, who fabricated lead bricks for radiation shielding and produced customized nuts, bolts, and metal parts. A quarter century after Lamb had retired in 1969, Laboratory personnel still passed his handiwork every day: he forged the ladder rungs on the smokestacks at the Laboratory.

In 1945, Miles Leverett purchased a second-hand rolling mill to initiate the rolling, casting, and forging of fuel elements and metal parts of reactors and recruited metallurgists for materials research. Declaring that "an integrated program on the properties and possibilities of materials from the structural and nuclear point of view is greatly to be desired," in 1946 Wigner hired William Johnson from Westinghouse as a consultant on the formation of a Metallurgy Division. Johnson recruited a half dozen metallurgists to form the division under the leadership of John Frye, Jr.

Metallurgists at the Laboratories faced the challenge of fabricating reactor components of uranium and aluminum alloys, beryllium, zirconium, and other exotic metals, and conducted intensive research into the functioning of metallic elements under high temperatures and radiation stress in reactors. Starting with fewer than a dozen staff members, the Metallurgy Division grew in time to as many as 300 people; and in 1952 Frye organized a group under John Warde as a ceramics laboratory. It fabricated crucibles, insulators, fuel elements, and customized parts for reactors, purified graphite for molds, developed vitreous enamels, and conducted significant ceramics research. It employed scientists and engineers and also a practical potter or two to make molds.

HIGH-FLUX BIOLOGY

Like the atom's nucleus for physical scientists, the living cell became the center of attention for life scientists during the postwar years. The graphite reactor furnished an abundance of economical radioisotopes to supplement the radium tracers and cumbersome devices used earlier to investigate life processes within cells. Radioactive tracers wrought a revolution in the life and medical sciences, fostering an understanding of metabolic processes and allowing a probing of cells down into the double strands of genetic heritage. This flux in biological sciences and the imperative need for a better understanding of the effects of radiation led Wigner to expand the biology and health physics organizations.

When John Wirth, head of the Health Division, returned to the National Cancer Institute in September 1946, Wigner and Lum split the Health Division into two new divisions and a medical department headed by physician Jean Felton and later by Thomas Lincoln. In October, Wigner selected Alexander Hollaender to head a Biology Division. Hollaender took degrees in physical chemistry from the University of Wisconsin, became a biophysicist studying the effects of radiation on cells at the National Institutes of Health, and studied the use of ultraviolet light for the control of airborne diseases. To dispel some of the mysteries surrounding nuclear technology, Hollaender's initial research plan at the Laboratories called for the study of radiation's effects on living cells, including such cell constituents as proteins and nucleic acids.

Beginning with a few radiobiologists studying microorganisms and fruit flies in crowded rooms behind the Laboratories' dispensary, Hollaender initiated a broad program that would make his division the largest biological laboratory in the world at one time, uniting programmatic mission research with fundamental biological sciences and fusing physics, chemistry, and mathematics with quantitative biology. To accomplish this mission, he recruited widely to staff the initial six research units in biochemistry, cytogenetics, chemical physiology, physiology, radiology, and cooperative groups. Including such well-known scientists as William Arnold, Waldo Cohn, Richard Kimball, and William and Liane Russell, the Biology Division had seventy scientists and technicians on staff by 1947. Lacking space at the X-10 site, Hollaender moved the new division into vacant buildings at the Y-12 plant.

The biological research that attracted the most public interest was the genetic experiments conducted under the supervision of William and Liane Russell, who used mice to identify the long-term genetic implications of radiation exposure for human beings. From the division's early scientific accomplishments, however, Hollaender took special pride in the discovery of the electronic nature of energy transfer reactions in photosynthesis, the discovery of the nucleotide linkage in RNA, and the discovery of messenger RNA. The Biology Division's greatest long-term influence on science may have come from its cooperation with the University of Tennessee-Oak Ridge Graduate School of Biomedical Sciences and with biological departments of universities throughout the nation and overseas. This effort brought Hollaender and the division an international reputation.

The second division broken out of the old Health Division in 1946 was Health Physics, with Karl Morgan as its director. Health Physics soon included seventy personnel engaged in service, research, and education. The service section provided area monitoring and furnished personnel with improved radiation detection devices. Early research included studies of radioisotopes discharged into river systems, estimation of thermal neutron tolerances, and new methods to detect radiation.

In 1944, Oak Ridge health physicists trained personnel responsible for radiation protection at Hanford. They continued this schooling at Oak Ridge until 1950 when the AEC established fellowships for graduate study at Vanderbilt and Rochester universities. The Army, Navy, and Air Force also sent personnel to receive health physics training at Oak Ridge. Because the Health Physics Division monitored radiation over the Laboratories in aircraft and boated the Clinch River to measure radiation entering from White Oak Creek, it was said to have its own "army, air force, and navy."

HIGH-FLUX EDUCATION

In late 1945, Martin Whitaker met with University of Tennessee officials to discuss a science education partnership to retain young scientists by permitting them to complete graduate work at the university while working at Clinton Laboratories. This program was the precursor of a large cooperative graduate program with the University of Tennessee that continued and expanded.

In 1946, the Oak Ridge Institute of Nuclear Studies, a nonprofit corporation of fourteen (later twenty-four) southeastern universities, was chartered with William Pollard as its director. In 1947, the Institute became a government-owned, contractor-operated facility of the AEC. Under its aegis, Ralph Overman of the Laboratory offered classes to train scientists in the use of radioisotopes. These classes soon were supplemented by a clinical facility using radioisotopes for cancer treatment.

In 1949, the Institute obtained support from the AEC to open the American Museum of Atomic Energy in a wartime cafeteria building. In 1974, the museum, renamed the American Museum of Science and Energy, moved into a new building adjacent to the corporate headquarters of the Oak Ridge Institute of Nuclear Studies, which itself had been renamed Oak Ridge Associated Universities and now had nearly 50 sponsoring members.

Universities that joined the Institute were invited to use the scientific facilities available at the Laboratory. Under the management of Russell Poor, the Institute began a program for faculty research at the Laboratory in the summer of 1947 with two participants. The number of participants increased to seventy by 1950, a level maintained for many years. Supplementing this research program were traveling lectures and seminars conducted by Laboratory scientists at the participating universities. The resulting interaction between Laboratory scientists and university faculties, along with faculty and student use of research equipment available at the Laboratory, contributed significantly to a spectacular growth in graduate science education throughout the South during the postwar years.

HIGH-FLUX TRAINING IN DOGPATCH

In August 1946, Eugene Wigner opened the Clinton Training School at the Laboratories with Frederick Seitz as its director. Although Wigner envisioned it as a small postdoctoral seminar in nuclear technology, more than fifty people from the military, industry, and academia enrolled. Among the first participants were Herbert MacPherson, Sidney Siegel, John Simpson, Everitt Blizard, Douglas Billington, Donald Stevens, and others who subsequently became renowned for research at the Laboratory and in science generally. The most famous graduate, however, was Captain Hyman Rickover of the U.S. Navy.

The Navy had first provided Wigner and Szilard funding for nuclear experiments in 1939, and during the war, Navy scientists developed a thermal diffusion process for separating uranium isotopes; the S-50 plant in Oak Ridge was built for this purpose. Navy interest in using nuclear energy for ship propulsion continued, and in early 1946 Philip Abelson of the Navy research team spent months at Clinton Laboratories studying Wigner's and Weinberg's approach to reactor design. In May 1946, Admiral Chester Nimitz assigned five Navy officers and three civilians to Oak Ridge. The officers were Hyman Rickover, Louis Roddis, James

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Dunford, Raymond Dick, and Miles Libbey. Rickover later recalled his Oak Ridge experience:

> When I started at Oak Ridge in 1946, there were 4 other naval officers along with me and 3 civilians. Each was sent to Oak Ridge individually, and each started working on his own....As soon as I got to Oak Ridge, I realized that if we ever were going to have atomic powerplants in the Navy, I would have to assemble these people and train them as a group. And I used a very simple expedient; I arranged to write their fitness reports, so once they knew I was writing their fitness reports, they started paying attention to me. So once I did that, then I was able to weld them into a team and teach them specialized duties in order to get ready for building a submarine plant. Well, the first attempt at building a powerplant at Oak Ridge was a civilian one, and it failed, then unofficially I persuaded the people, the engineers, and the scientists, who were engaged in that enterprise, without any formal permission, to start working on a submarine plant, and they did this for a while. Meanwhile, I advised the Chief of the Bureau of Ships to retain this group of trained people together, and as soon as we came back to Washington, to have us start working on a submarine plant.

Under Rickover's exuberant direction, the Navy group enrolled in the Training School attended every seminar, interviewed every scientist willing to talk, and wrote bundles of reports that became the paper foundation of the nuclear Navy. Legends about Rickover's activities at Clinton Laboratories still abound. For example, he sometimes elicited information from scientists by introducing himself: "I'm Captain Rickover; I'm stupid."

With the end of Monsanto management and the return of Wigner and Seitz to their universities in 1947, the Clinton Training School ceased to exist. Despite its brief tenure, the school was responsible for launching a long and fruitful relationship between the Navy and the Laboratory. Rickover entered into several nuclear design contracts with the Laboratory and he often employed Laboratory scientists, such as Theodore Rockwell, Frank Kerze, and Jack Kyger, on Navy projects. Everitt Blizard, a civilian who had accompanied Rickover to Oak Ridge, remained at the Laboratory, where he supervised investigations of reactor shielding. For years, Rickover provided Alvin Weinberg with unsolicited advice on Laboratory management. He also strongly supported the formation and instructional work of the Oak Ridge School of Reactor Technology housed at the Laboratory between 1950 and 1965.

CRITICAL EXPERIMENTS

By his own account, Wigner's most troublesome problems as research director emanated from the Army bureaucracy. In the postwar years, the Army continued its wartime security policies. This meddlesome oversight made the exchange of scientific data with Hanford and Los Alamos difficult for Wigner and his research staff. This and similar problems caused Wigner to have several confrontations with Army authorities, notably Colonel Walter Leber.

Colonel Walter Leber had replaced Captain James Grafton as the Army representative for Clinton Laboratories in May 1946, and he employed a large staff to monitor its activities. His office staff included twenty-two people to inspect construction and administration, three to investigate security breeches, and twenty-nine to examine research and development. This large group audited even minor details, down to the book titles ordered by the library. Their actions soon alienated both Laboratory scientists and Monsanto executives. James Lum strenuously objected to Leber's efforts to "interfere and assume responsibilities which are reserved only for Monsanto under the present contract." To reduce confusion and improve communications, Lum and Wigner asked Edgar Murphy, formerly an Army major, to serve as a liaison with Leber's staff.

Tensions continued, however, notably in the case of critical experiments Wigner wished to undertake to test the use of beryllium as a neutron trap or reflector. He encountered a "Catch 22" situation created by Leber's interpretation of a regulation the Army had imposed after Louis Slotin lost his life during a critical experiment at Los Alamos. Wigner insisted the tests were completely safe, but Leber required that the debilitating regulations, which brought the tests to a virtual standstill, be meticulously observed. Only after review at the highest level were the experiments allowed to continue. Such delays discouraged Wigner and in time caused him to return to university life.

HIGH-FLUX SCIENCE

"Speaking as individuals who have been interested in radiation effects on solids since the conception of the first large reactors," Wigner and Frederick Seitz wrote, "we find it gratifying that a phenomenon which originated as a pure nuisance promises to provide us with useful information about the solid state in general and about many of the materials we use every day."

By "nuisance," they meant the swelling and distortion of graphite under the bombardment of nuclear fission, an effect predicted by Wigner and thus called the "Wigner disease." Concern about the effects of this "disease" on the graphite reactor at Oak Ridge and similar reactors at Hanford stimulated intense interest in solid state physics at Clinton Laboratories and elsewhere in the postwar years. As suggested earlier, this fascination played a role in Wigner's formation of the Metallurgy Division and in his personal attention to neutron scattering experiments and to the investigations of zirconium.

Although aluminum had served as cladding for uranium in the graphite and other early reactors, it was not suitable for use in the high-temperature reactors designed in the late 1940s. Metallurgists considered substituting zirconium, a metal that resists corrosion in water at high temperatures. Zirconium, however, seemed to have an affinity for absorbing neutrons, ultimately "poisoning" nuclear reactors.

In 1947, Wigner authorized a group of Laboratory researchers to study this problem. Wigner devised a "pile oscillator" to move materials regularly in and out of a reactor. Using a washing machine motor to power such an oscillator, Herbert Pomerance later that year discovered zirconium's affinity for neutrons was vastly overstated, chiefly a result of its contamination by the element hafnium.

Zirconium minerals have traces of hafnium, which is nearly identical in characteristics to zirconium, making economical separation of the two difficult. With funding from Captain Rickover and the Navy, many laboratories investigated ways to separate the two elements. In 1949, chemical technologists at the Y-12 plant, under the direction of Warren Grimes, identified a successful separation technique, and scaled it to production under the management of Clarence Larson, then superintendent of Y-12.

Zirconium alloys became essential first to the Navy's reactors and later to commercial power reactors. Zirconium rods filled with uranium pellets comprised the fuel cores of nearly all light water reactors, and hafnium became important in the control rods used to regulate nuclear reactions.

As authorities on solid state physics, Wigner and Seitz were intrigued by the interaction of radiation with materials, especially the neutron scattering experiments of Ernest Wollan and Clifford Shull, which used a beam of neutrons from the graphite reactor. With a modified x-ray diffractometer that Wollan installed at a beam hole of the graphite reactor in late 1945, Wollan and Shull systematically studied the fundamentals of thermal neutron scattering by crystalline powders. One of the early problems in these investigations was the large amount of diffuse neutron scattering that was observed.

Experiencing difficulty in making sense of the diffuse scattering from various forms of carbon--diamond dust, graphite powder, and charcoal--they called on Wigner for advice. Shull later recalled:

> I well remember a discussion that Ernie and I had with Eugene Wigner, then the research director of the laboratory and a physicist of infinite wisdom and physical intuition, about this puzzling feature. After listening to our tale of woe and reflecting on the problem, he surprised us very much by calmly suggesting "maybe there is something new here, and maybe we have to relax our notions about conservation of particles." I can only say that I came away from that meeting with the feeling that Wigner had more faith in our experiments than perhaps Ernie and I had!

After a few months' additional experimentation, Wollan and Shull recognized that the consistency of their data had been distorted by spurious multiple scatterings in the specimens being investigated, an effect unfamiliar to both of them. This breakthrough allowed them to pursue their studies, which established neutron diffraction as a quantitative research tool fostering scientific knowledge of crystallography and magnetism. Their work built the foundation on which neutron scattering programs have been developed throughout the world. Although a half century has passed since the initial experiments, neutron scattering remains an important and active area of research.

HIGH-FLUX MANAGEMENT

In late 1945, the War Department drafted a bill to continue military control of atomic research and energy. Atomic scientists at Chicago and Oak Ridge vigorously opposed the measure and formed federations to lobby for civilian control. After a protracted political battle, the enactment of the Atomic Energy Act of 1946 established civilian control by a five-member AEC. With David Lilienthal, formerly chairman of the Tennessee Valley Authority, as its first chairman, the AEC assumed control from the Manhattan District in January 1947. While this high-level political struggle was in progress, the disposition of the facilities built by the Manhattan District, including Clinton Laboratories, was at issue as well.

In early 1946, General Groves appointed a committee of prominent scientists to plan the Manhattan District's nuclear activities and budget for 1947. This committee urged the expansion of research and development for both the production of fissionable materials and the advancement of nuclear power. To accomplish these tasks, the committee suggested awarding contracts to university and private laboratories for unclassified fundamental research. On the other hand, the committee urged that classified research and studies requiring equipment too expensive or products too hazardous for a university to handle be conducted by national laboratories. As the committee viewed it, each national laboratory should have a board of directors from universities in its region that would form associations to sponsor research and perhaps become the contracting operators.

The committee initially recommended only two national laboratories, one at Argonne near Chicago and another serving the Northeastern states. It expected the eventual formation of a national laboratory in California, but it ignored the Southeast and other regions.

Led by George Peagram and Isidor Rabi of Columbia University, universities in the Northeast campaigned to acquire a national laboratory. The Radiation Laboratory at the Massachusetts Institute of Technology had closed at the war's end, and the Substitute Alloy Materials Laboratory at Columbia University had been moved to the K-25 plant in Oak Ridge. Columbia and other northeastern universities urged the relocation of Clinton Laboratories to the Northeast, and some scientists at Clinton Laboratories liked the idea. More importantly, General Groves was amenable to it, and he selected an old army post on Long Island as the future site of Brookhaven National Laboratory.

In April 1946, the University of Chicago agreed to operate Argonne National Laboratory, with an association of Midwestern universities providing research sponsorship. Argonne thereby became the first "national" laboratory. It did not, however, remain at its original location in the Argonne forest. In 1947, it moved farther from the "Windy City" to a new site on Illinois farmland. When Alvin Weinberg visited Argonne's Director, Walter Zinn, in 1947, he asked Zinn what kind of reactor was to be built at the new site. When Zinn described a heavy-water reactor operating at one-tenth the power of the materials testing reactor under design at Oak Ridge, Weinberg joked it would be simpler if Zinn took the Oak Ridge design and operated the materials testing reactor at one-tenth capacity. It proved unintentionally prophetic.

Clinton Laboratories' rural ambiance did not please the urbane Robert Oppenheimer, Isidor Rabi, and James Conant, influential members of the AEC's scientific advisory committee. Early in 1947, Oppenheimer declared that "Clinton will not live even if it is built up." Perturbed by this attitude, Charles Thomas of Monsanto demanded improvements in Monsanto's operating contract at the Laboratories. On a no-profit, no-loss basis, the contract's chief attractions for Monsanto were the inside knowledge it provided on nuclear reactor advances and the public relations benefits it accrued for the company as a result of its selfless efforts to protect the nation's security and advance the nation's technological capabilities.

Such virtues had their limits, especially when the war's outcome was no longer at stake. During the 1947 contract renewal negotiations, Thomas requested that Monsanto be allowed to profit from the contract by increasing its maximum fee for services from $65,000 a month to $100,000 a month. This request was not well received at the AEC; moreover, Thomas's request to build the materials testing reactor near Monsanto's Dayton laboratory or near its headquarters in St. Louis rather than Oak Ridge was unacceptable. In May 1947, Thomas and Monsanto decided not to seek to renew the contract for operating Clinton Laboratories when it expired in June. The company, however, agreed to serve on a month-to-month basis until the AEC secured another contract operator.

Loss of the contract at Clinton Laboratories did not mar Charles Thomas's career. In early 1948, he signed a contract to operate the new AEC plant at Miamisburg near Dayton, later named the Mound Laboratory. That same year, he was elected president of the American Chemical Society, and in 1951 he became president of Monsanto. His director at Clinton Laboratories, James Lum, left for Australia in August 1947 to build an aspirin factory. Thomas made Lum's assistant, Prescott Sandidge, the Laboratories' executive director, pending final contract closure. Colonel Walter Leber, temporary director for the Army, left in the summer of 1947 as well, later becoming Ohio River Division commander for the Corps of Engineers and governor of the Panama Canal Zone.

In the summer of 1947, when Wigner returned to "monastic" life at Princeton, the Laboratory was left without a research director. Thomas decided to leave selection of Wigner's successor to the new contract operator. He requested that Edgar Murphy, Wigner's assistant, coordinate research pending selection of a new contractor and director.

Of his work at the Laboratory in 1946 and 1947, Wigner later lamented: "Oak Ridge at that time was so terribly bureaucratized that I am sorry to say I could not stand it. The person who took over was Alvin Weinberg, and he slowly, slowly improved things. I would not have had the patience."

BLACK CHRISTMAS

Because the Argonne and Brookhaven laboratories would be operated by associations of universities, William Pollard and the Oak Ridge Institute of Nuclear Studies considered assuming Monsanto's contract. The AEC, however, preferred that the University of Chicago resume its operation of Clinton Laboratories, and it announced in September 1947 that a contract would be negotiated with Chicago. The university thereby would become contract operator of both the Argonne National Laboratory and Clinton Laboratories, which was renamed Clinton National Laboratory in late 1947 while negotiations with Chicago were underway.

The AEC was willing to enter a four-year contract with the university. Negotiations floundered, however, over the division of responsibilities between the university and the AEC for personnel policies, salaries, auditing, and oversight. Moreover, the university decided to recruit a new director and management team for the Laboratory, despite pleas for the return of Wigner. William Harrell, the university business manager, paraded prominent scientists to the Laboratory for orientation; but when offered the director's position, all demurred. Near the end of 1947, Warren Johnson, wartime chief of the Laboratory's Chemistry Division, agreed to serve as the interim director, but only temporarily.

Concerned that the AEC's research program might become too academic, Lilienthal established a committee of industrial advisors for the AEC, and during a November visit to Oak Ridge, he discussed with Clark Center of Union Carbide Company the possibility that the company assume management of the Laboratory. Union Carbide managed the nearby Y-12 and K-25 plants, and it already had a staff and offices in Oak Ridge that could easily add the Laboratory to their responsibilities. In addition, Union Carbide wanted to resolve its labor union troubles. Workers at K-25 had joined a CIO union, while craftsmen at the Laboratory had joined an AFL union. A December 1947 strike over wages and benefits at K-25, which were lower there than those at the Laboratory, threatened the company's tranquility and productivity. By assuming the Laboratory's management, Union Carbide possibly could abate labor tension.

With Lilienthal ill and bed-ridden and other AEC commissioners on holiday excursions, Carroll Wilson, the AEC's general manager, made the decision on Christmas Eve to replace the University of Chicago with Union Carbide. At the same time, he decided to centralize all reactor development at Chicago's Argonne National Laboratory, transferring responsibility for the MTR Oak Ridge high-flux reactor to Argonne. The day after Christmas, the AEC concurred with these decisions. Wilson went to St. Louis to persuade Monsanto to hang on at Oak Ridge an additional two months until Union Carbide could become sufficiently organized for the task. To James Fisk, director of research, fell the lot of carrying the message to Oak Ridge, where he received the welcome one would expect for a bearer of ill-tidings.

Remembered in the Laboratory long afterward as "Black Christmas," the shock came during the round of holiday parties. Reaction to the surprise was caustic. "Deck the Pile with Garlands Dreary," followed by several bawdy verses, reverberated through the hills. "It was rapid-fire and rough," admitted Lilienthal. He went on to say, "The people at Clinton Lab engaged in fundamental research felt they had been double-crossed, for we proposed to have Carbide & Carbon operate the lab (what was left of it, *i.e.*, minus the high-flux reactor), and this caused great anguish, not only among the chronic complainers but quite generally."

Laboratory staff declared the decisions represented a demotion from national laboratory status to a radioisotopes and chemical-processing factory. The leaders of the Oak Ridge Institute for Nuclear Studies fired messages to President Truman and the AEC protesting the decisions as a blow to southern scientific aspirations.

This thinking ignored the AEC's promise to continue fundamental research at the Laboratory, specifically in physics, chemistry, biology, health physics, and metallurgy. Rather than reducing its status, in January 1948, the official name became Oak Ridge National Laboratory, ending the use of "Clinton" which had been the nearest town during project construction.

The first impact of the decisions on the Laboratory was the transfer of the Power Pile Division studying the Daniels pebble-bed reactor to Argonne National Laboratory. Before leaving Oak Ridge, the division had begun studying Rickover's naval reactor, and Harold Etherington, Samuel Untermeyer, and others in the group subsequently gained recognition with their designs of a reactor prototype for the atomic-powered *Nautilus* submarine and for an early breeder reactor.

The AEC never released a precise definition of "National Laboratory." It granted the title, however, only to laboratories that engaged in broad programs of fundamental scientific research, and that had extensive facilities open to scientists outside the laboratories and cooperated with regional universities in extensive science education efforts.

Oak Ridge clearly qualified for national laboratory rank, becoming one of three initial national laboratories. Argonne and Brookhaven laboratories were rebuilt in 1948 on new sites, making Oak Ridge the oldest national laboratory on its original site.

Located in the Appalachian mountains far from the bright lights of any metropolis, Oak Ridge from its earliest days has had to prove that its location was worthy of its purpose. Surviving in an environment of political and administrative intrigue has required institutional perseverance and ingenuity--qualities that have served the Laboratory's science and management well.

CHAPTER III

THE ACCELERATING LABORATORY

"Discovering why radiation does what it does to inorganic, organic, and living matter will benefit the entire world," declared biochemist Waldo Cohn as he speculated about the Laboratory's research agenda after the war.

A vital question facing the Laboratory in the years following World War II was how to obtain the wherewithal to pursue such research. After all, the Laboratory's brief history had been devoted largely to supporting development of the atomic bomb and, although scientists had touted peaceful applications of the atom, there were no assurances that the government would be willing to shift its administrative gears and resources to such research.

One answer to the Laboratory's postwar research dilemma came from an unexpected source: investigations into nuclear-powered aircraft sponsored by the Atomic Energy Commission (AEC) and partially funded by the U.S. Air Force. The plane never got off the ground, but the research directed toward this effort lifted the level of scientific knowledge in biology, genetics, and physics, and of technologies related to reactors, computers, and accelerators to new heights.

FLIGHTS OF FANCY

Fantasies about the future applications of atomic power abounded just after World War II. Popular writing and art, which depicted atomic-powered ships, submarines, aircraft, trains, automobiles, and even farm tractors, stimulated public interest. These popular images came into sharp focus at Oak Ridge, where the Laboratory participated in the development of nuclear-powered submarines, aircraft, and ships during the late 1940s and 1950s.

The application of atomic power to motion and travel became a centerpiece of the Laboratory's research program in the postwar era. Efforts to devise nuclear-powered transport, especially aircraft and submarines, involved nearly every Laboratory researcher. This research, in turn, contributed to the design of three nuclear reactors, the adoption of high-speed digital computers, and the acquisition of particle accelerators for nuclear physics. Moreover, the efforts fueled the Laboratory's budget and staffing, both of which also increased during the late 1940s and early 1950s under the management of its new contract operator, Union Carbide Corporation.

In February 1950, the Laboratory acquired some of the laboratories located at the Y-12 plant. This union strengthened and diversified the Laboratory's research efforts. One result: projects designed to build reactor-driven machines that could travel over land, work underwater, and perhaps even fly. In the process, the Laboratory helped to turn the public's postwar atomic dreams into concrete demonstrations of atomic energy's potential contributions to society. And the investigations of atomic travel supplied funding for basic research in biology, physics, genetics, and computer science that in time proved more useful than the primary goal itself. Like a physically fit marathon runner who never reaches the finish line but finds value in trying, the Laboratory found strength and purpose in seeking goals that often proved unattainable.

Acquiring the research divisions from the Y-12 plant upped the Laboratory staff by fifty percent and, by 1953, more than 3600 people worked there. Moreover, the divisions coming from Y-12 had strong capabilities in applied science and heavy industrial technology. The Laboratory also benefitted from the transfer of state-of-the-art hardware. For example, the Laboratory acquired a von Neumann computer for data handling and built cyclotrons that could accelerate heavy ions to high speeds.

ACCELERATED ADMINISTRATION

The Laboratory's added responsibilities, personnel, and equipment created new challenges in management and administration. In 1948, the Carbide and Carbon Chemical Division of Union Carbide Company (later its Union Carbide Nuclear Division) became the Laboratory's operations contractor. Union Carbide enjoyed two advantages that would serve both the company and the Laboratory well. First, the company's expertise in chemical engineering fit the tasks it would be asked to accomplish. Second, Union Carbide was no stranger to Oak Ridge.

Since 1943, it had managed a large staff that operated the K-25 gaseous diffusion plant and, in 1947, the government extended Union Carbide's responsibilities to the Y-12 production facilities. Thus, when the AEC called on Union Carbide to oversee Laboratory research activities in December 1947, it placed all Oak Ridge operations under unified management.

Union Carbide soon proved its mettle both to the AEC and Laboratory personnel. Under the arrangement, Carbide executives --both at the corporation's international headquarters in New York City and at its regional headquarters in Oak Ridge--set Laboratory's work rules and pay scales. Virtually the entire Laboratory staff went on Union Carbide's payroll. For its services, Union Carbide received a fixed fee from the AEC that amounted to less than two percent of the Laboratory's annual budget.

Union Carbide appointed Nelson Rucker as the Laboratory's new executive director. A graduate of Virginia Military Institute, Rucker joined Union Carbide in 1933 to manage a Carbide plant in West Virginia. He moved to Oak Ridge with Carbide in the early 1940s and remained there throughout the war. At the time of his appointment to the position of Laboratory executive director, he was serving as Y-12's plant manager.

Rucker was responsible for overseeing the Laboratory's daily activities. Playing a role comparable to that of a city manager, he saw that the institution functioned efficiently on a day-to-day basis, but he did not set its long-term agenda. That responsibility belonged to the Laboratory's scientific research director, a job that Union Carbide had as much difficulty filling in the late 1940s as the University of Chicago had had a few years earlier. Several prominent scientists rejected the position; Frederick Seitz, for instance, declined because the Laboratory had lost its reactor projects to Argonne. In December 1948, Carbide asked Alvin Weinberg to take the job. He also declined, citing his youth and lack of experience, but agreed to become the associate director for research and development.

A biophysicist, Alvin Weinberg had studied the fission of living cells at the University of Chicago during the late 1930s. In 1941, he joined the Metallurgical Project to investigate nuclear fission. As an assistant to Eugene Wigner, he participated in wartime reactor designs and, in May 1945, at Wigner's advice, moved to Oak Ridge to join the Laboratory's Physics Division, where he succeeded Lothar Nordheim as division chief in 1947. Weinberg, whose ability to communicate his thoughts in writing was exceeded only by his rare scientific talent, captured both the spirit of excitement and confusion that existed in the Laboratory during the late 1940s when he wrote Wigner about his responsibilities as head of the Physics Division. "I feel in my new job a little bit like a trick horse-back rider at a circus," Weinberg told Wigner. "The idea seems to be to ride standing on three or four spirited horses, all of which are interested in going in different directions."

Limited work space constituted a major challenge facing Rucker, Weinberg, and other Union Carbide managers in 1948. During the postwar turmoil, the AEC suspended new construction and often deferred maintenance on existing structures, pending the government's decision on the Laboratory's future. This wait-and-see attitude, which made sense given the uncertainties in Washington, continued while wartime frame structures deteriorated swiftly. The only new facilities erected at the Laboratory between 1946 and 1948 were surplus Army quonset huts to relieve overcrowding, plus an electric substation and steam power plant built in futile anticipation that the proposed materials testing reactor would be built in Oak Ridge.

Overcrowding became serious in 1948 as the Laboratory added new divisions, hired more personnel, and installed new equipment. These events led physicist Gale Young to complain, "In accumulating technical people which it cannot use for lack of accommodations, I believe that the Laboratory has embarked on a course which is suicidal to itself and detrimental to the national interest. Until considerably more buildings have been erected, staff reductions, rather than increases, are in order."

In 1949, with the Laboratory's future on a firmer, more stable footing, the AEC budgeted $20 million for new construction, and Union Carbide initiated its "Program H" to replace wooden wartime structures with more permanent brick and mortar. In addition to paving streets, landscaping the grounds, and renovating older structures, about 250,000 square feet of new office and laboratory space opened in the early 1950s. Among the new facilities, three were of particular importance: Building 4500, the Laboratory's principal research building and administrative headquarters; a radioisotope complex, consisting of ten buildings designed for the processing, packing, and shipment of the Laboratory's most valuable material export; and a pilot plant for use in the Laboratory's work on chemical processing. With this new construction, the AEC and Union Carbide gradually hoisted the Laboratory out of the East Tennessee mud.

REACTOR ACCELERATION

The AEC's 1947 decision to centralize reactor development at Argonne National Laboratory proved ill considered. Argonne's mandate from the AEC to support Navy reactor development and new programs for civilian power and breeder reactors strained its resources and capabilities. It therefore supported Oak Ridge's efforts to continue design and fabrication work in East Tennessee in order to concentrate on its own development responsibilities in Chicago. Taking advantage of this unexpected turn of events, in 1948, Oak Ridge urged the AEC to build the materials testing reactor on the Cumberland Plateau twenty miles from Oak Ridge. The AEC, however, acquired a site in Idaho and, four years later, the newly built materials testing reactor at the Idaho National Engineering Laboratory began successful operation under the supervision of Richard Doan, formerly the research director at

Oak Ridge. Even so, two years before the reactor in Idaho began operation, the Laboratory had the world's first solid fuel and light water reactor at work in Oak Ridge. Despite the government's intentions to end reactor work at the Laboratory, the facility's deeply rooted efforts in the development of this technology refused to wither.

While designing the materials testing reactor in 1948, the Laboratory built a small mockup of the reactor to test the design of its controls and hydraulic systems. In 1949, Weinberg proposed installing uranium fuel plates inside the mockup to test the reactor design under critical conditions. The AEC staff feared that Weinberg's initiative might become an opening wedge for a revived reactor program at Oak Ridge. "We have no plans," Weinberg reassured them, "to convert the critical experiment into a reactor." The mockup experiment at Oak Ridge in February 1950 produced the first blue Cerenkov glow of a nuclear reaction underwater ever seen, and it provided superb training for those who were to serve subsequently as operators for the full-scale reactor in Idaho. LITR

As its reactor program burgeoned, the AEC relaxed its previous plans to centralize reactor development and construction at Argonne National Laboratory and the Idaho National Engineering Laboratory. In fact, the AEC allowed the Laboratory to upgrade the mockup's shielding and cooling systems. These improvements raised the system's capacity to 3000 thermal kilowatts, only one-tenth of the materials testing reactor's maximum power but still useful for experiments. Labeled the "poor man's pile" by Wigner, the mockup formally became the Low Intensity Testing Reactor. Experiments conducted there established the feasibility of the boiling water reactor, which later became one of the design prototypes for commercial nuclear power plants. Operated remotely from the graphite reactor control room, the "poor man's pile" served the Laboratory until 1968 when the AEC shut it down after a long, useful life.

FLYING REACTORS

During the early 1950s, the Laboratory made a major entrance into reactor development through efforts to design a nuclear airplane using funds drawn largely from the U.S. Air Force. British and German development of jet engines at the end of World War II had given quick, defensive fighters an advantage over slower long-range offensive bombers. To address the imbalance, General Curtis LeMay and Colonel Donald Keirn of the Air Force urged the development of nuclear-powered bombers. In 1946, they persuaded General Groves to approve Air Force use of the empty S-50 plant near the K-25 plant in Oak Ridge to investigate whether nuclear energy could propel aircraft. S-50

The initial concept called for a nuclear-propelled bomber that could fly at least 12,000 miles at 450 miles per hour without refueling. Such range and speed would enable nuclear weapons to be delivered via airborne bombers anywhere in the world. The aircraft, however, would require a compact reactor small enough to fit inside a bomber and powerful enough to lift the airplane, complete with shielding to protect the crew from radiation, into the air.

Under Air Force contract, the Fairchild Engine and Airplane Corporation then established a task force at S-50 to examine the feasibility of nuclear aircraft, and arranged with Research Director Eugene Wigner to obtain scientific support from the Laboratory. Everitt Blizard, a Navy scientist who came to the Laboratory in 1946 with Hyman Rickover, remained to study radiation shielding for the crews of nuclear submarines. Blizard expanded his submarine research in 1949 to include the lightweight shielding needed for airborne reactors.

Initial studies conducted by the Fairchild Corporation at S-50 showed promise and, in 1948, the AEC asked the Massachusetts Institute of Technology (MIT) to evaluate the feasibility of nuclear-powered flight. MIT sent scientists to Lexington, Massachusetts, for a summer's appraisal, and they reported that such flight could be achieved within fifteen years if sufficient resources were applied to the effort. In September 1949, the AEC approved the Laboratory's participation in an aircraft nuclear propulsion project; Weinberg was made project director and Cecil Ellis was made coordinator. Raymond Briant, Sylvan Cromer, and Walter Jordan later served as directors of the Laboratory's Aircraft Nuclear Propulsion (ANP) project.

Soon after the Laboratory acquired its nuclear propulsion project, General Electric took over the work of Fairchild and relocated it from Oak Ridge to its plant in Ohio. Although some Fairchild personnel transferred to Ohio, about 180 remained in Oak Ridge to join the Laboratory's aircraft project in May 1951. Among those who decided to stay in East Tennessee were Francois Kertesz, a multilingual scientist; Edward Bettis, a computer wizard before the age of computers; William Ergen, a reactor physicist; Fred Maienschein, later the director of the Engineering Physics and Mathematics Division; and Don Cowen, who headed the Laboratory's Information and Reports Division.

Much of the Laboratory's initial aircraft work focused on the development of adequate, yet lightweight shielding that would protect airplane crews and aircraft rubber, plastic, and petroleum components from radiation. Knowing a nuclear aircraft would never get airborne carrying the seven-foot thick walls typical of research reactor shields, Blizard and his team worked two shifts daily, testing potential lightweight shielding materials in the lid tank atop the graphite reactor. As the research progressed, however, the graphite reactor proved inadequate to meet the level of research activity. To continue its shielding investigations, the Laboratory added two unique nuclear reactors to its fleet.

First, in December 1950, the Laboratory completed its two-megawatt bulk shielding reactor at a cost of only $250,000. BSR

To build this reactor, the Laboratory modified its earlier materials testing reactor design to create what became popularly known as the "swimming pool reactor." This reactor's enriched uranium core was submerged in water for both core cooling and neutron moderation. From an overhead crane, the reactor could be moved about a concrete tank, the size of a swimming pool, to test bulk shielding in various configurations. The Laboratory later placed a ten-kilowatt nuclear assembly (named the pool critical assembly) in one corner of the pool to permit small-scale experiments without tying up the larger reactor. The Laboratory standardized this inexpensive, safe, and stable design, which became a prototype for many research reactors built at universities and private laboratories around the world. Upgraded with a forced cooling system in 1963, it supplanted the graphite reactor (retired that year) and proved extremely useful for irradiating materials at low temperatures.

PCA

TSF

A second Laboratory reactor resulting from the nuclear aircraft project was the tower shielding facility completed in 1953. Cables from steel towers could hoist a one-megawatt reactor in a spherical container nearly 200 feet into the air. Because no shielding surrounded the reactor when it was suspended, it operated under television surveillance from an underground control room. Containing uranium and aluminum fuel plates moderated and cooled by water, the "tower" reactor helped scientists answer questions about the effects of radiation from a reactor flying overhead. A tower-suspended reactor minimized the ground-based scattering effects, which made shielding measurements derived from a conventional reactor unreliable. It thus helped researchers better understand the type and amount of shielding that would be needed aboard a nuclear aircraft.

Experiments indicated that a divided shield, consisting of one section around the aircraft's reactor and another around its crew, would comprise a combined weight less than a single thick shield blanketing the aircraft's reactor. Researchers, however, could never devise a reactor and shielding light enough to ensure safe flight. The tower shielding facility reactor later was upgraded and shielding experiments continued there for forty years and were still being performed in 1992, long after visions of a nuclear aircraft had faded from memory.

AIRCRAFT REACTOR

The bulk and tower shielding reactors were designed to test materials that might be used on a nuclear-powered aircraft. For the U.S. Air Force, improved materials represented a means toward an end: a nuclear-powered engine able to drive long-range bombers to take-off speeds and propel them around the world. To achieve this goal, the Laboratory designed an experimental 1000-kilowatt aircraft reactor as a demonstration. This small reactor engine, operating at high temperatures, used molten uranium salts as its fuel, which flowed in serpentine tubes through an eighteen-inch reactor core. The heat it produced was dissipated through a heat exchanger to the atmosphere. In 1953, the Laboratory constructed a building to house this experimental reactor and its related components.

To contain molten salts at high temperatures within a reactor, the Laboratory developed a nickel-molybdenum alloy, INOR-8, which derived its name from its developer, Henry Inouye (IN) of Oak Ridge (OR) National Laboratory. Able to resist corrosion at high temperatures while it retained acceptable welding properties, the alloy was later commercialized by private industry (an early example of technology transfer) to supply tubing, sheet, and bar stock for a variety of industrial applications. The aircraft reactor also compelled Laboratory personnel to learn how to perform welding with remote manipulators and how to remotely disassemble molten salt pumps. Laboratory researchers devised two salt reprocessing schemes, as well, to recover uranium and lithium-7 from spent reactor fuel.

The first test run of the aircraft reactor experiment took place in October 1954. In accordance with the plans, the reactor ran at one megawatt for a hundred hours. Donald Trauger and other observers of the reactor's operations recall that the reactor core, pumps, valves, and components literally became "red hot." Completion of the design, fabrication, and operation of such an exotic nuclear reactor in five years was considered a noteworthy event, and dignitaries such as General James Doolittle, Admiral Lewis Strauss, and Captain Hyman Rickover visited Oak Ridge to see the red-hot reactor in action. Its success led the Laboratory to propose additional study of this reactor concept and the design of a larger sixty-megawatt, spherical prototype, known as the "fireball reactor," to conduct more sophisticated experiments. Laboratory researchers, for example, asked what would happen if a pilot decided to fly the plane upside down while irradiated molten liquid pulsated through the engine. More significantly, they wondered what would happen if the airplane exploded in mid air?

Three unique reactors were not the only hardware the Laboratory acquired as a result of its nuclear aircraft project. The project helped justify the construction of a critical experiments facility to test reactor fuels and a physics "hot" laboratory to study the effects of radiation on solid materials. It also encouraged the Laboratory in efforts to acquire its first nuclear particle accelerators and digital computers.

Because the success of nuclear flight depended on expensive and complex hardware on the ground, the Laboratory benefited from being on the receiving end of a well-funded government project. However, the Laboratory's ability to take advantage of this situation also depended on the skill of its research and support staff and the managerial expertise of its leaders. Internal administrative adjustments, including the acquisition of the Y-12 research divisions in 1950, also helped.

Y-12 LABORATORIES ACQUIRED

By 1950, all parties--the government, the Laboratory, and the company--largely viewed Union Carbide's management of the Laboratory as a success. Recognizing that staff loyalties resided with the Laboratory, Carbide did not attempt to convert them to "company men." It eagerly identified and rewarded ambitious Laboratory staff (elevating some to managerial positions), undertook sorely needed facility reconstruction and expansion, and fostered basic and applied sciences. "Carbide management has demonstrated," asserted one manager, "that first-rate basic research can be done in an industrial framework."

When Nelson Rucker, Carbide's executive director of Laboratory operations, transferred to a plant in West Virginia in 1950, a major reorganization ensued. Alvin Weinberg, formerly associate director, became the Laboratory's research director, and Clarence Larson, formerly the Y-12 plant manager, became the Laboratory's new executive director. A chemist from Minnesota, Larson had worked at the University of California's radiation laboratory before moving to Oak Ridge to become the Y-12 research director in 1943 and superintendent in 1948. An able manager and accomplished scientist, Larson strengthened and broadened the Laboratory's research activities.

Before Larson's appointment, Union Carbide considered moving the Laboratory to Y-12, where the Biology Division already occupied a building. By 1950, however, the chilling tensions of the Cold War and the heated battles of the Korean War sparked a rapid expansion of nuclear weapons production, which increased the workload at Y-12 and K-25 and led to the construction of new gaseous diffusion plants at Paducah, Kentucky, and Portsmouth, Ohio. As a result, space became precious at Y-12 and plans to move the Laboratory there were aborted. Thus the Laboratory's acquisition of Y-12's three research divisions--Isotope Research and Production, Electromagnetic Research, and Chemical Research --left everyone and everything in the same place. However, the administrative realignment meant that Y-12 researchers in these divisions would now report to Laboratory management.

STABLE ISOTOPES

By 1950, the Laboratory was distributing more than fifty different radioisotopes free of charge to qualified cancer research centers. Cobalt-60, essential to cancer research and therapy, was a prime isotope on the Laboratory's distribution list. When the Laboratory began to ship isotopes overseas, the AEC approved a cooperative arrangement between the Laboratory and the Oak Ridge Institute of Nuclear Studies to train foreign scientists in radioisotope research. The Laboratory's isotope research efforts were further advanced through the merger of Y-12's Isotope Research and Production Division with the Laboratory's Isotopes Division. This union added stable, nonradioactive isotopes to the Laboratory's catalog.

The Y-12 stable isotopes program had emerged at the end of the war when the Y-12 staff ceased using calutrons to separate uranium isotopes for atomic weapons. Eugene Wigner then urged the continued use of some calutrons to separate the stable isotopes of all elements. "We should have as the very basis of future work in nuclear physics and chemistry, knowledge of the various cross-sections of pure stable isotopes," he argued. The AEC approved Wigner's proposal, and a group led by Clarence Larson, Christopher Keim, and Leon Love had begun to separate the isotopes of stable elements.

Researchers at first used four calutrons salvaged from electromagnetic equipment. Stable isotope research and development required modifications to the calutrons, better understanding of the obscure chemistry of less common elements, spectroscopic analysis of nuclear properties, and advances in the use of isotopes as tracers. All of this was accomplished by the group at Y-12.

Christopher Keim, a group leader, later recalled that copper isotopes were the first to be collected. Using copper-65 as the source material, George Boyd and John Swartout made nickel-65, identifying it as a nickel isotope with a half-life of 2.6 hours. "All that had to be done," Keim modestly explained, "was to put copper chloride into the charge bottle, heat it with uranium tetrachloride, lower the magnetic field, and space the collector slots to receive the copper-63 and copper-65 ion beams."

Isotopes of iron, platinum, lithium, mercury, and other stable elements were separated and shipped to university, government, and industrial laboratories worldwide to aid basic research in physics, chemistry, earth sciences, biology, and medicine. They became especially valuable to medical science, for which they were converted into radionuclides used in scanners to diagnose cancer, heart disorders, and other diseases affecting human internal organs and bones. Contributing to basic scientific knowledge and enhancing the quality of human life, the Laboratory's stable isotopes program continued on an expansive scale until the 1970s, generating substantial revenue from sales.

PARTICLE ACCELERATORS

In 1950, the Y-12 Electromagnetic Research Division, under Robert Livingston, became the Laboratory's Electronuclear Division and switched from studies of calutrons to fundamental research on the formation and motion of ions in electric fields. The Electronuclear Division was also in charge of the cyclotrons used for particle acceleration. At the same time, Arthur Snell and the Physics Division entered the particle acceleration field as well, using the electrostatic accelerators popularly called "atom smashers." Thus the Laboratory, during the early 1950s, pursued two independent lines of particle acceleration--cyclotrons in the Electronuclear Division and electrostatic machines in the Physics Division. This hot pursuit of fast moving subatomic particles was propelled by rapid postwar advances in the basic science of nuclear physics.

In 1946, the Laboratory proposed to purchase a large betatron accelerator to join the hunt for elusive subatomic particles. This purchase required the approval of the Army, and the resulting delays made the 160-ton betatron obsolete when it finally arrived. Saddled with an outdated piece of equipment, the Laboratory sold it as surplus to another agency. By 1948, however, the Laboratory's nuclear aircraft program, with support from the U.S. Air Force, was inching down the runway. This project added impetus for accelerator research because of the need to understand the subatomic effects of radiation on shields and other materials that would be part of the aircraft.

In 1948, Arthur Snell, director of the Physics Division, asked Wilfred Good and Charles Moak to start an accelerator program using materials readily and inexpensively available at the Laboratory and Y-12. "The objective was clear," recalled Good. "Neutrons were the key to the new frontier of applied nuclear energy; to fully exploit neutrons, their behavior had to be thoroughly understood; and the Van de Graaff was the only known source of neutrons of precisely determined energies." The Chemistry Division had acquired a 2.5-MV Van de Graaff electron accelerator from the Navy. Richard Lamphere of the Instrumentation and Controls Division converted it into a 3-MV proton accelerator that could bombard lithium targets with protons to produce a stream of neutrons. This little Van de Graaff accelerator supported research for thirty years, its most important service to science coming when John Gibbons and his colleagues used it to confirm a theory that atomic elements originated through nucleosynthesis in the centers of stars.

To test radiation effects at energies lower than those generated by the Van de Graaff, the Laboratory also acquired a Cockcroft-Walton accelerator, an early particle accelerator named for its inventors. The Laboratory installed these first accelerators in an abandoned powerhouse.

In March 1949, Alvin Weinberg and Herman Roth of the AEC met Air Force commanders and contractors to discuss priorities in the nuclear aircraft research program. After concluding that a 5-MV Van de Graaff accelerator was needed, the Air Force agreed to purchase it if the Laboratory constructed a building to house it. First installed at Y-12 plant, the 5-MV Van de Graaff accelerator produced its first beam in 1951, making it the world's highest-energy machine of its kind. In 1952, the Laboratory completed a high-voltage laboratory building and moved the three linear particle accelerators into it. A decade later, it added a 15-MV tandem Van de Graaff accelerator to extend the energy capability of the existing machines and to accelerate ions heavier than helium.

CYCLOTRON ACCELERATION

While Arthur Snell and members of the Laboratory's Physics Division concentrated on particle acceleration through direct-current high-voltage machines, Robert Livingston and the

Y-12 electromagnetic team pursued an independent course of achieving acceleration with cyclotrons. Invented in 1930 by Ernest Lawrence, cyclotrons had two D-shaped electrodes (dees) in a large and nearly uniform magnetic field. The dees operated at high electric currents and were alternately positive or negative. They accelerated the charged particles (ions) and the magnetic field confined them to a circular orbit. Cyclotrons were the forerunners of the giant synchrotrons of the 1990s, and during their sixty years of development they increased the energy of protons (nuclei of hydrogen atoms) from one million electron volts to twenty trillion electron volts. The cost of the machines also multiplied from $100,000 each to $10 billion.

Having built calutrons during the war for the electromagnetic separation of uranium isotopes, Livingston and his associates at the Y-12 plant had abundant experience and took advantage of the ample supply of unused electromagnets lying about the plant after the war. During the late 1940s and early 1950s, they built three cyclotrons to study the properties of compound nuclei and heavy particle reactions. The cyclotrons were identified by their diameters measured across the dees as the 22-inch, 63-inch, and 86-inch machines.

Livingston's team built the 22-inch, 2-MV cyclotron in the late 1940s to test how electromagnets in calutrons could be used and how high-current calutron ion source techniques could be applied to cyclotron functioning. The cyclotron served its purpose and later was doubled to 44 inches for testing new ion sources, new beam-focusing methods, and ways to increase the intensities of accelerated beams.

An 86-inch cyclotron began operation in November 1950, performing radiation damage studies for the nuclear aircraft project. As the world's largest fixed-frequency proton cyclotron, it produced a proton beam four times more intense than any other cyclotron; its blue beam projected through the air as much as sixteen feet, visibly impressing visitors. Bernard Cohen, chief physicist for this machine, used it to study proton-induced nuclear reactions and to supply the isotope polonium-208 until a commercial source became available.

This was the era of hydrogen bomb development, and the question arose whether a powerful hydrogen bomb might ignite nitrogen in the atmosphere, causing an Earth-bound holocaust. To find the answer, the AEC asked the Laboratory to build a cyclotron that would accelerate nitrogen ions. The Laboratory asked Alex Zucker, a newly minted Ph.D. from Yale University, to develop a source of multiply charged nitrogen ions. After successfully completing this task, he was directed to build a cyclotron to measure the cross section of the nitrogen-nitrogen reaction and thereby determine whether the atmosphere would burn. Built in a year and a half at a cost of $150,000, the cyclotron became operational in 1952. Zucker and his collaborators, Harry Reynolds and Dan Scott, soon demonstrated that a hydrogen bomb would not immolate the earth. They then turned the cyclotron into a basic research instrument, the world's first source of energetic heavy ions, which opened nuclear interactions of complex nuclei as a new field of scientific investigation.

The Laboratory's first cyclotrons were the most economical ones ever built because the Electronuclear Division used surplus electromagnetic equipment that required little modification. Because the Y-12 calutron tracks had been placed side by side in vertical formation, the Laboratory's cyclotrons were marked by their unique vertical mounting, instead of the horizontal position of the dees found at other laboratories. These pioneering cyclotrons helped advance the technology of high-beam currents, which have since been the force behind the Laboratory's versatile isochronous, a variable energy cyclotron completed in 1962, and still later the Holifield heavy-ion research facility completed in 1980.

INFORMATION ACCELERATION

The aircraft nuclear propulsion project, together with the reactors and particle accelerators developed to support it, generated immense quantities of scientific data that required rapid analysis. This need stimulated the Laboratory's interest in electronic computers, which became available during the 1940s. In 1947, Weinberg created a Mathematics and Computing Section within the Physics Division under the direction of Alston Householder, a mathematical biophysicist from the University of Chicago, who, in

1948, converted the section into an independent Mathematics Panel to manage the Laboratory's acquisition of computers.

Before 1948, complex, multifaceted computations at the Y-12 and K-25 plants were done on electric calculators and card programming machines. Because of its participation in the nuclear aircraft project, the Laboratory obtained through the Fairchild project a matrix multiplier to solve linear equations. At the Laboratory's urging, the AEC also leased Harvard University's early Mark I computer. Householder and Weinberg insisted that the Laboratory should also acquire its own "automatic sequencing computer" to be used by staff scientists doing difficult computations for the nuclear aircraft project. The computer, they contended, could also serve and educate university faculty and researchers visiting the Laboratory. When purchased, it became the first electronic digital computer in the South.

Householder and the Laboratory's leadership were familiar with the pioneering work of Wigner's friend, John von Neumann, who had pursued experimental computer development near the end of the war for the Navy. Admiral Lewis Strauss thought the Navy needed computers to aid in weather forecasting so vital to ships at sea and, with his urging, the Navy in 1946 sponsored the fabrication of the first von Neumann digital computer at Princeton University. After considering Raytheon and other commercial computers, the Laboratory and Argonne National Laboratory decided to build their own von Neumann-type computers, tailored specifically to help solve nuclear physics problems.

Engineers from the Laboratory assisted Argonne during the early 1950s in the design and fabrication of the Oak Ridge Automatic Computer and Logical Engine. Its name was selected with reference to a lyrical acronym from Greek mythology --ORACLE, defined as "a shrine in which a deity reveals hidden knowledge."

Assembled before the development of transistors and microchips, ORACLE was a large scientific digital computer that used vacuum tubes. It had an original storage capacity of 1024 words of 40 bits each (later doubled to 2048 words); the computer also contained a magnetic-tape auxiliary memory and an on-line cathode-tube plotter, a recorder, a typewriter, and a rapid magnetic tape. Operational in 1954, for a time it had the fastest speed and largest data storage of any computer in the world. Problems that would have required two mathematicians with electric calculators three years to solve could be done on ORACLE in twenty minutes.

Householder and the Mathematics Panel used ORACLE to analyze radiation and shielding problems. In 1957, Hezz Stringfield and Ward Foster, both of the Budget Office, also adopted ORACLE for more mundane but equally important tasks--annual budgeting and monthly financial accounting. As one of the last "homemade computers," ORACLE became obsolete by the 1960s, and the Laboratory thereafter purchased or leased its mainframe computers from commercial suppliers. From the initial applications of ORACLE to nuclear aircraft problems, computer enthusiasm spread like lightning throughout the Laboratory and, in time, use of the machines became common in all the Laboratory's divisions.

PARTICLE COUNTING

Scintillation spectrometers and multichannel analyzers were other machines that benefited from--and contributed to--the Laboratory's involvement with the nuclear aircraft project and its concomitant studies of atomic particle behavior and radiation damage.

In 1947, German scientists observed that some crystals emitted flashes of light when struck by radiation beams and that the intensity of the flash was proportional to the radiation's energy. By 1950, a scientific team at the Laboratory led by P.R. Bell devised an improved scintillation spectrometer to facilitate measurement of the number and intensity of light flashes emanating from crystals exposed to radiation. Electronic recording of these measured flashes with multichannel analyzers permitted complete and rapid energy analysis of gamma ray or particle radiation.

Bell's group later converted the scintillation spectrometer into a medical pulse-height analyzer and developed a "scintiscanner" and an electronic probe to assist physicians using radioisotopes to locate tumors in their patients without surgery. In 1956, Bell's team received funding from the AEC to continue this work, and they formed a Medical Instruments group in the Laboratory's Thermonuclear Division at Y-12, where they primarily investigated fusion energy. Later, they incorporated electronic computers in medical scanners to improve diagnostic techniques. Commercial versions of the machines they invented became common at major medical centers throughout the world.

Research in the solid state sciences at the Laboratory just after the war received a boost from the radiation damage studies conducted under the auspices of the nuclear aircraft project in the early 1950s. Prolonged exposure to radiation alters the properties of solids, and often compromises their ability to serve as structural material in a reactor. Degeneration is caused by defects in the crystalline lattices created by collisions with high energy particles within the radiation field.

"Inasmuch as a thorough understanding of the normal behavior of solids is necessary for a complete understanding of the effects induced by nuclear radiation in metals and other solids," Laboratory physicist Douglas Billington declared in 1950, "studies in related solid state fields are being carried on in conjunction with the radiation effects experiments." Billington headed a Physics of Solids Institute that was established in 1950 by joining the Solid State Section in the Physics Division with the Radiation and Physical Metallurgy Section in the Metallurgy Division. South of the graphite reactor building, a Physics of Solids laboratory was completed in 1950 to pursue radiation damage and related solid state investigations. In 1952, the institute became the Solid State Division. In a few years, it substantially expanded fundamental knowledge of radiation damage in solids. One notable discovery to come out of this research was made by Mark Robinson and Ordean Oen, who identified the "channeling" phenomenon in which energetic particles move, relatively undisturbed, long distances parallel to rows and planes of atoms in a solid.

Investigations of radiation damage in connection with shielding and reactor development also became central to the early work of the Laboratory's Biology Division at the Y-12 plant. Biologists learned that nucleoproteins, the complex substances present in living cell nuclei and essential to normal cell functioning, were highly sensitive to radiation; paper chromatography and ion-exchange methods used to separate and analyze compounds could help scientists and medical researchers measure and gauge this sensitivity. From these studies came valuable new information about radiation's impacts on cells, the composition of malignant tissues, and other basic problems in biology and medicine.

After applying ion exchange chromatography to the separation of fission products and starting the Laboratory's radioisotopes program, Waldo Cohn used a similar technique to separate and identify the constituents of nucleic acids. One of his discoveries indicated that ribonucleic acid (RNA) had the same general structure as deoxyribonucleic acid (DNA), a concept that had international impact on molecular biology and the understanding of genetics.

OF MICE AND MAMMALS

By 1949, the Laboratory had 10,000 mice housed in renovated facilities at the Y-12 plant. Research on the mice, led by the Biology Division's William and Liane Russell, was designed to advance understanding of radiation effects on mammals. According to William Russell, mice were used for genetic studies because they had few diseases, were economical to feed and maintain, had a rapid reproduction rate, and had the essential organs found in human beings. Liane Russell's 1950 survey of the gestation period of mice, which examined their sensitivity to radiation, yielded valuable information about critical periods during embryo development. She showed that radiation-induced mutations of cells were more likely to occur during gestation. Largely because of her discovery of the greater radiation sensitivity of embryos, women have been cautioned about X-ray examinations during pregnancies.

The Russells, a cosmopolitan husband and wife team from England and Austria, came to Oak Ridge in 1948 from Bar Harbor, Maine. They expected Oak Ridge to be a backward community with minimal social and cultural opportunities. The Biology Division had an international clientele, however, and Liane Russell was surprised by the extent to which the world beat a path to Oak Ridge and the Laboratory. The Russells became renowned for taking their international guests on mountain hiking trails. They later played important roles in the creation of the Big South Fork

National River Recreation Area, a wilderness preserve just north of Oak Ridge.

As the Biology Division had an international reputation, the Oak Ridge School of Reactor Technology established in 1950 enjoyed national prestige. Because at that time the subject was security-sensitive and could not be taught in universities, the AEC, with considerable support from Captain Rickover and the Navy, sponsored this school for outstanding engineers and scientists. Frederick VonderLage, the school's first director, was a former Navy officer who had taught physics at the Naval Academy. The faculty included Laboratory staff, and the school's text consultant was Samuel Glasstone, who published several classic texts on nuclear reactor technology.

The fifty members of the first class at the school in 1950 came from the AEC, government contractors, and the armed services; the second class came largely from industries needing trained personnel in reactor engineering and operations; later, college graduates planning to work in the nuclear industry were accepted. Students took courses in reactor technology that covered reactor neutron physics, radiation damage, and experimental reactor engineering. They spent a year in Oak Ridge and supplemented their classroom training with part-time research assignments at the Laboratory. After two semesters, students would load fuel in the movable assembly in the bulk shielding "swimming pool" reactor, plotting the curve as fuel was added and the flux increased; they then compared the onset of critical mass with their predictions. Later, they spent a summer investigating specific problems, often analyzing a reactor design under consideration by the AEC and then submitting a thesis on its feasibility.

The school expanded during the 1950s, occupying a new building completed by the Laboratory in 1952 and specializing in advanced subjects not taught at universities. Under director Lewis Nelson, the school in 1957 joined six universities in offering a standard two-year curriculum. At the end of the decade, it enrolled its first international students. Five years later, the school closed when university science and engineering programs became equal to the task. Of its 986 enrollees during the school's fifteen years of instruction, only ten did not complete the course.

FLYING HIGH

When Union Carbide assumed management of the Laboratory, the graphite reactor was the only nuclear reactor on the Oak Ridge reservation. By 1953, the Laboratory had three reactors operating, two nearing completion, and several others in various stages of planning and development. In addition, it had high-speed computers, high-energy cyclotrons and Van de Graaff particle accelerators. Equally important, the Laboratory had succeeded in assembling an aggressive research staff that worked with a sense of urgency rivaling that of the war years.

As the Laboratory expanded its reactor and shielding programs in response to the nuclear aircraft project and acquired the Y-12 research organization in the early 1950s, administrative realignment became necessary. Electronics experts from the Physics Division, for example, moved into an Instrumentation and Controls Division, and the Shielding group under Blizard became a separate Neutron Physics Division (later renamed the Engineering Physics Division). Solid state scientists under Douglas Billington formed a separate Solid State Division, and the Mathematics Section under Alston Householder became an independent division. Similar organizational changes took place in chemistry, reactor technology, and other Laboratory research pursuits.

ORG

By 1953, Laboratory personnel numbered 3600, more than double the wartime peak; the staff was divided into fifteen research and operating divisions. "I am sometimes appalled by the size and scope of our operation here," Weinberg admitted privately to Wigner. "It seems that we have become willy-nilly victims, in a particularly devastating way, of the big operator malady."

In response, Wigner advised Weinberg to appoint deputy and assistant research directors to assist with central management. Weinberg accepted the advice. John Swartout, director of the Chemistry Division, became Weinberg's assistant in 1950 and deputy director in 1955. Other assistant research directors of the early 1950s included Elwood Shipley, Charles Winters, Robert

Charpie, Ellison Taylor, and George Boyd. "There is," observed Weinberg, "a hierarchy of responsibility in which management on each level depends on the integrity and sense of responsibility of the next level to do the job sensibly and well." This line of responsibility from individual to group leader to section chief to division director to assistant or associate director to Laboratory director was to remain the prevailing administrative framework within the Laboratory during the ensuing decades.

The prime force behind the Laboratory's expansion during the early 1950s ended in 1957, when Congress objected to continuing the costly nuclear aircraft project in the face of supersonic aircraft and ballistic missile development that made the nuclear aircraft concept obsolete. In response to this congressional decision, the Laboratory shelved its aircraft shielding and reactor prototype investigations. In 1961, President John Kennedy canceled the remainder of the nuclear aircraft project.

The scientific data gleaned for the aircraft project, however, soon proved useful when the Laboratory undertook the design of a molten salt reactor for electric power production. As Laboratory metallurgist George Adamson summarized it, "The program quite literally didn't get off the ground, but out of it grew the base for the high temperature materials technology needed by NASA and in several industrial fields."

Although the nuclear aircraft project stalled, the Laboratory's participation in efforts to apply nuclear energy to acceleration continued briefly in consultation with the Maritime

Commission, which in 1957 built a nuclear-powered merchant ship. The 21,000-ton ship propelled by a pressurized-water reactor was a floating laboratory, demonstrating the feasibility of commercial ships propelled by nuclear energy. At the Laboratory, Alfred Boch headed a Maritime Reactors group providing technical review of the ship reactor design, while other Laboratory units assisted with on-board health monitoring, environmental studies, and waste disposal. Completed in July 1959, the *N.S. Savannah* could remain at sea for 300,000 miles without refueling, clearly proving the scientific-engineering feasibility of such ships. Nuclear-powered ships, however, could not compete economically with oil-fired vessels; thus, the *N.S. Savannah* became the first and last U.S. ship of its kind.

In the 1960s, the Laboratory became involved in nuclear-power studies for the national space program, and in the 1980s it studied space reactors for the strategic defense initiative. Despite these efforts, it is fair to say that the Laboratory's work on the *N.S. Savannah* marked the end of its nuclear transportation programs. Postwar dreams of nuclear-powered trains, automobiles, aircraft, and tractors ended, but the scientific findings that evolved from these endeavors moved forward in other areas in the years ahead.

CHAPTER IV

THE OLYMPIAN LABORATORY

A symbol of peaceful international competition in the ancient world, the Olympics were revived in modern times, not only in quadrennial athletic performances but also in scientific competitions. Sparked in 1953 by President Dwight Eisenhower's call for international cooperation in the peaceful uses of atomic energy, scientists worldwide showcased their achievements at international conferences, which resembled the athletic Olympics, in 1955 and 1958. In these competitions, the world-class research at Oak Ridge National Laboratory often took the laurels.

Science during the 1950s became a full-blown instrument of foreign policy, both in Cold War weapons competition and in peaceful applications of nuclear science, especially nuclear fission reactors and fusion energy devices. As an international center for nuclear fission research, by the mid-1950s, the Laboratory had as many as six reactors under concurrent design and construction. The Laboratory's chemical technology expertise also made it a leader in reactor fuel reprocessing and recovery. Both these programs earned the Laboratory much prestige at the 1955 scientific olympics. Also, in 1958, the Laboratory's tiny fusion energy research effort vaulted above larger programs elsewhere to win the gold at the second international conference on peaceful uses of the atom.

The Laboratory and other Atomic Energy Commission (AEC) facilities also ascended the ladder of experimental reactor development in 1953. That year, the Laboratory's experimental homogeneous reactor first generated electric power. Elsewhere, other nuclear mileposts were passed: a demonstration atomic reactor to propel submarines and an experimental breeder reactor began operating in Idaho, and the first university research reactor was unveiled at North Carolina State University.

In a dramatic speech on the future of the atom to the United Nations in 1953, President Eisenhower pledged the United States "to find the way by which the miraculous inventiveness of man shall not be dedicated to his death, but consecrated to his life." The president's "Atoms for Peace" speech, hailed throughout the world as a prologue to a new chapter in the history of nuclear energy, was to guide the research efforts of the AEC and the Laboratory for years to come. The initiative, Alvin Weinberg declared, would make nuclear science the "touchstone of peace."

Soon after his seminal address, President Eisenhower signed the 1954 Atomic Energy Act fostering the cooperative development of nuclear energy by the AEC and private industry. In response, the AEC began a massive declassification of nuclear science data for the benefit of private users, and the Laboratory assumed a key role in the AEC's five-year plan to develop five new demonstration nuclear reactors. Launched in 1954, the AEC plan called for the construction of a small pressurized water reactor by Westinghouse Corporation; an experimental boiling water reactor by Argonne National Laboratory; a fast breeder reactor, also by Argonne; a sodium-graphite reactor by North American Aviation; and an aqueous homogeneous fuel reactor by the Oak Ridge Laboratory.

Beyond its work on the homogeneous reactor, the Laboratory in the 1950s--as a national center for chemistry and chemical technology--also focused on developing fluid fuels for nuclear reactors. In this experiment, the Laboratory concentrated on three possible options: fuels in solution, fuels suspended in liquid (slurries), and molten salt fuels. Each of these options posed fundamental challenges in chemistry and chemical technology. Moving confidently from solids to liquids to gas in support of the AEC efforts on behalf of the atom, the Laboratory also conducted research for heterogeneous, solid fuel reactors, providing conceptual designs for a transportable army package reactor, a maritime reactor, and a gas cooled reactor.

The Cold War and President Eisenhower's "Atoms for Peace" speech re-energized and refocused the Laboratory's research efforts. In effect, it gave the Laboratory a multifaceted research agenda, many aspects of which were tied to the development and application of nuclear power. Summarizing the impact of the nation's postwar aims on the work of the Laboratory, Director Clarence Larson commented, "1954 has witnessed the transition that many of us have hoped for since the war. The increasing emphasis on peacetime applications of atomic energy," he went on to say, "has been a particular source of gratification."

AQUEOUS HOMOGENEOUS REACTOR

In addition to the nuclear aircraft reactor, the bulk shielding reactor, and the tower shielding facility built as part of its aircraft nuclear project for the Air Force, the Laboratory had three other major reactor designs in progress during the mid-1950s: its own new research reactor with a high neutron flux; a portable package reactor for the Army; and the unique reactor called the aqueous homogeneous reactor because it combined fuel, moderator, and coolant in a single solution (designed as one of five demonstration reactors under the auspices of the AEC).

Initial studies of homogeneous reactors took place toward the close of World War II. It pained engineers to see precisely fabricated solid fuel elements of heterogeneous reactors eventually dissolved in acids for the removal of fission products, the "ashes" of a nuclear reaction. Chemical engineers hoped to design liquid fuel reactors that would dispense with the costly destruction and processing of solid fuel elements. The formation of gas bubbles in liquid fuels and the corrosive attack of the high temperature fuels on materials, however, presented daunting design and materials challenges.

With the additional help of experienced chemical engineers brought to the Laboratory after its acquisition of Y-12 laboratories in 1950 and the encouragement of Union Carbide manager George Felbeck, the Laboratory proposed to address these design challenges. Rather than await theoretical solutions, Laboratory staff attacked the problems empirically by building a small, cheap experimental homogeneous reactor model.

A homogeneous (liquid fuel) reactor had two major advantages over heterogenous (solid fuel and liquid coolant) reactors. Its fuel solution would circulate continuously from the reactor core through a processing plant that would remove unwanted fissionable material. Thus, unlike a solid fuel reactor, a homogeneous reactor would not have to be taken off-line periodically to discard spent fuel. Equally important, a homogeneous reactor's fuel, or more precisely the solution in which it was dissolved, could serve as the source of power generation and for energy transport. For these reasons, a homogeneous reactor held the promise of simplifying nuclear reactor designs.

A building to house the experimental homogeneous reactor was completed in March 1951. The first model for testing the feasibility of a homogenous reactor used uranyl sulfate fuel. After plugging leaks in the high temperature pressure piping system, the power test run began in October 1952, and the design power level of one megawatt was attained in February 1953. The reactor's high pressure steam twirled a small turbine that generated 150 kilowatts of electricity, an accomplishment that earned its operators the honorary title, "Oak Ridge Power Company."

HRE

Marveling at the homogeneous reactor's smooth responsiveness to power demands, Weinberg found its initial operation thrilling. "Charley Winters at the steam throttle did everything, and during the course of the evening we electroplated several medallions and blew a steam whistle with atomic steam," he exulted in a report to Wigner, asking him to bring von Neumann to see it. Despite his enthusiasm, Weinberg found AEC's staff decidedly bearish on homogeneous reactors and, in a letter to Wigner, he speculated that the "boiler band wagon has developed so much pressure that everyone has climbed on it, pell mell." In other words, Weinberg surmised that the AEC was committed to the development of solid fuel reactors and Laboratory demonstrations of other reactor types—regardless of their success—were not likely to alter its course of actions.

Nevertheless, the Laboratory dismantled its first homogeneous model reactor in 1954 and obtained authority to build a large pilot plant with "a two-region" core tank. The aim was not only to produce economical electric power but also to irradiate a thorium blanket surrounding the reactor, thereby producing fissionable uranium-233. If this pilot plant proved successful, the Laboratory hoped to accomplish two major goals: to build a full-scale homogeneous reactor as a thorium "breeder" and to supply cheap electric power to the K-25 plant for enriching uranium.

Initial success stimulated international and private industrial interest in homogeneous reactors and, in 1955, Westinghouse Corporation asked the Laboratory to study the feasibility of building a full-scale homogeneous power breeder. British and Dutch scientists studied similar reactors, and the

Los Alamos Laboratory built a high temperature homogeneous reactor using uranyl phosphate fluid fuel. If the Laboratory's pilot plant operated successfully, staff at Oak Ridge thought that homogeneous reactors could become the most sought-after prototype in the intense worldwide competition to develop an efficient commercial reactor. Proponents of solid fuel reactors, the option of choice for many in the AEC, would find themselves in the unenviable position of playing catch up.

ARMY PACKAGE REACTOR

Similar initial success flowed from studies at the Oak Ridge School of Reactor Technology, where a study group in 1952 proposed a compact, transportable package reactor for generating steam and electric power at military bases so remote that supplying them with bulky fossil fuels was too difficult and costly. The AEC and Army Corps of Engineers expressed a great deal of interest in this concept and, in early 1953, Laboratory management met with Colonel James Lampert and Army Corps of Engineers staff to initiate planning for such a mobile reactor. Alfred Boch, Ed Gross, and a team in the Electronuclear Division were given the responsibility for designing this small reactor. They selected a heterogeneous, pressurized water, stainless steel system design that could use standard components wherever possible for easy replacement at remote bases. Walter Jordan led a Laboratory team that drew up specifications for a package reactor capable of generating ten megawatts of heat and two megawatts of electricity. General Samuel Sturgis, Chief of the Army Engineers, decided to build the reactor at Fort Belvoir, Virginia, where his officers could be trained to operate it.

The package reactor was the first reactor built under bid by private contractors. The Army Corps of Engineers, in fact, received eighteen bids that ranged from $2.25 million to $6.9 million. The Corps awarded the contract to Alco Products (American Locomotive Company) in December 1954, and Alco completed the reactor in 1957.

With a core easily transportable in a C-47 airplane, the package reactor could generate power for two years without refueling, compared to the 54,000 barrels of diesel fuel that an oil-fired plant would consume in the same time. The Army later built similar package reactors for power and heat generation in the Arctic and other remote bases.

PURIFICATION

Ancient athletes considered the Olympics a purifying experience. Purification was also a preoccupation of scientists who participated in the nuclear olympics of the 1950s--not personal purification, but fuel purification to enable nuclear reactors to operate more efficiently.

Although designers of the homogeneous reactor hoped to achieve simultaneous reactor operation and fuel purification, other Laboratory technologists led by M.D. Peterson, Frank Steahly, and Floyd Culler sought improved methods of purifying spent fuels and recovering valuable plutonium and uranium from spent fuel elements. The Laboratory's interest in Culler's efforts was reflected by the subdivision of its Technical Division into the Reactor Technology and the Chemical Technology divisions in February 1950. The Reactor Technology Division carried out Laboratory responsibilities for reactor development, while the Chemical Technology Division, following Culler's lead and the Laboratory's "separations and recovery" experience during and after World War II, sought to improve chemical separations processes.

The Laboratory's most important achievement during World War II had been the recovery of plutonium from graphite reactor fuel. Drawing on its wartime experience, the Laboratory attained notable success, during the postwar years, recovering uranium stored in waste tanks near the graphite reactor. The management at Hanford called on the Laboratory staff to address similar recovery problems at its plutonium production facilities in the state of Washington. The Laboratory also built a pilot plant to improve Argonne National Laboratory's REDOX process for recovering plutonium and uranium through solvent extraction. The pilot plant served as a prototype for an immense REDOX process plant completed at Hanford in 1952. To recover uranium from fuel plates at the AEC's Idaho reactor site, the Laboratory devised the so-called "25 process." A large plant using this process was completed there, also in 1952.

Recovery, separation, and extraction--the primary components of fuel purification--were big business at the Laboratory during the 1950s. Such efforts played a major role in developing the Plutonium and Uranium Extraction (PUREX) process selected in 1950 for use at the Savannah River reactors. Two huge PUREX plants were built at Savannah River in 1954 and a third at Hanford in 1956. Later, large plants using the PUREX process were built in other nations, and some Laboratory executives believe the PUREX process, in the end, may have constituted the Laboratory's greatest contribution to nuclear energy.

By 1954, the Laboratory's chemical technologists had completed a pilot plant demonstrating the THOREX process for separating thorium, protactinium, and uranium-233 from fission products and from each other. This process could isolate uranium-233 for weapons development and also for use in the proposed thorium breeder reactors.

During the 1950s, the Laboratory's Chemical Technology Division served as the AEC's center for pilot plant development, echoing the Laboratory's wartime role in plutonium recovery and extraction. The succession of challenges it resolved--uranium-235 recovery, REDOX pilot plant, PUREX development, and THOREX pilot plant--swelled the ranks of the Chemical Technology Division from fewer than 100 people in 1950 to almost 200 in 1955. A similar expansion took place in the Analytical Chemistry Division. Its staff increased from 110 people to 214 people during the same period.

The fuel purification program brought Eugene Wigner back to the Laboratory in 1954. Wigner had been working for DuPont on the design of the Savannah River reactors when he agreed to return to Oak Ridge to apply his chemical engineering expertise to design a solvent extraction plant. Labeled "Project Hope," because it promised to extend the supply of fissionable materials for energy production, Wigner's 1954 study resulted in the design of a processing plant able to recover uranium-235 from spent fuel for reuse in reactors at a cost of $1 per gram, compared with the prevailing cost of $7.50 per gram of uranium from ore. His study helped turn the attention of the Laboratory's chemical technologists from improving individual processes for the recovery of uranium, plutonium, and thorium to developing an integrated plant capable of separating all nuclear materials at a single site. The proposed power reactor fuel reprocessing facility would have competed with private industry, however, and eventually the AEC decided not to construct it.

OAK RIDGE RESEARCH REACTOR

In 1953, the Laboratory received AEC approval to build a new research reactor. The reactor design, blueprinted by Tom Cole's team, combined features of the materials testing reactor and swimming pool reactor. With a thermal power rating of twenty megawatts, its neutron flux--the critical research element--was exceeded only by the materials testing reactor in Idaho.

After several construction delays, the new Oak Ridge research reactor was completed and reached its design power in March 1958. A flexible, high-performance reactor with an easy-to-access core, it proved useful for physics and materials research, irradiations, and neutron beam studies. Physicists Cleland Johnson, Frances Pleasonton, and Arthur Snell performed the research reactor's first scientific experiments. They examined the angular correlation between the neutrino and the electron in the decay of helium-6, thereby clarifying beta decay interaction and improving the recoil spectrometry technique pioneered by Snell and his colleagues.

During the reactor's thirty years of service, it supported many scientific advances too numerous to list and became a tourist attraction as well. An impressive structure, silhouetted by the blue glow of radiation emanating from the core within its protective pool, the Oak Ridge research reactor was admired in person by Senator John Kennedy, Congressman Gerald Ford, and other noted and aspiring political figures. Thanks to relaxed security requirements in the wake of President Eisenhower's call for international cooperation, the reactor also attracted many foreign scientists and dignitaries, such as the Queen of Greece and King of Jordan, who came to the Laboratory on other business but could not pass up an opportunity to see one of the facility's most notable achievements.

1955 GENEVA CONFERENCE

The Laboratory's new research reactor was being designed at the same time that plans were being made for the first United Nations Conference on Peaceful Uses of the Atom. That conference was scheduled for Geneva, Switzerland, in August 1955. Ostensibly, a staid, professional scientific meeting, organized in response to Eisenhower's "Atoms for Peace" initiative, in reality it was an extravagant science fair with exhibits from many nations emphasizing their scientific achievements. Never before had the accomplishments of nuclear power been placed on such a public stage. And never before had scientists so openly presented their findings as symbols of national prowess. Just as the athletic Olympics in the post World War II era emerged as peaceful arenas for venting Cold War animosities, the 1955 Geneva conference on the atom became a platform for assessing the relative strengths of science in capitalist and communist controlled societies.

Because critical comparisons of the exhibits, especially those brought by the Soviets and Americans, were expected, the AEC asked its laboratories for spectacular exhibit concepts. At Oak Ridge, Tom Cole's suggestion that the AEC build and display a small nuclear reactor was welcomed.

In early 1955, a Laboratory team led by Charles Winters designed and fabricated a scaled-down version of the materials test reactor, operating at one-hundred kilowatts instead of

1955

thirty megawatts. It became the first reactor to use low-enriched uranium dioxide fuel. After testing, the reactor was disassembled and shipped by air from Knoxville to Geneva, where the Laboratory team reassembled and tested it. Designed, built, tested, transported to Geneva, and reassembled in only five months, it became the most spectacular display at the conference, admired by political dignitaries such as President Eisenhower and Charles de Gaulle in person, as well as by the public and media. The reactor and the twenty-eight scientific papers presented to the conference by staff members gave the Laboratory the right to claim the laurels of the international competition.

Heralding the multi-faceted applications of peaceful atomic power, the Geneva conference captured the public's imagination. After the conference, the American exhibit returned home for a triumphant national tour, minus its most eye-catching element. The Swiss government purchased Oak Ridge's model materials testing reactor to use for research at a facility in Wurenlingen.

"Our Laboratory stands today as an institution of international reputation," exulted Alvin Weinberg, who became Laboratory Director shortly after the conference. "This we sense from our many distinguished foreign visitors," Weinberg continued, "from the numerous invitations which our staff receives to foreign meetings, and in the substantial part which we played at Geneva. But with international reputation," Weinberg cautioned, "comes international competition." And, as any Olympic champion will tell you, as difficult as it is to win the first gold medal, it is even more difficult to sustain a level of performance unequalled by others.

GAS COOLED REACTOR

International exchange brought the Laboratory a new assignment from the AEC: to explore gas cooled reactor technology. Although U.S. studies of gas cooled reactors waned with the termination of the Daniels Power Pile investigations in 1948, British scientists successfully designed and built several large gas cooled reactors in the early 1950s. In 1956, Congress directed the AEC to develop firsthand experience with gas cooled, graphite moderated reactors. In response, the AEC turned to the Laboratory, which formed a study team headed by Robert Charpie. The work of this team led to evaluations of the comparative costs of nuclear power produced by gas cooled and water cooled reactors.

The Laboratory's initial findings seemed promising. In 1957, the AEC made the Laboratory responsible for designing fuel elements for an experimental gas cooled reactor to be constructed in Oak Ridge. By early 1958, the Laboratory had completed a design for a helium cooled, graphite moderated reactor. Its core was to be uranium oxide clad in stainless steel, although a team led by Murray Rosenthal also studied graphite-coated particles as alternative fuel elements.

With the cooperation of the Tennessee Valley Authority, in 1959 the AEC began construction of an experimental gas cooled reactor on the shore of Melton Hill Lake near the Laboratory. This reactor was to serve as a power-generating prototype. Eight test loops inside the reactor would allow Laboratory scientists to test various fuel elements. Construction delays and increasing project costs, however, soon caused the test loops to be eliminated from the design. Then, in 1964, the AEC ordered the project stopped even though all construction on the reactor had been completed and its fuel elements had been manufactured and fully evaluated. The light-water reactor industry had advanced so rapidly that the Oak Ridge prototype could no longer serve the purposes for which it was planned. Despite initial promise, the AEC reactor design had become obsolete before it was operational.

MOLTEN SALT REACTOR EXPERIMENT

Another innovative nuclear reactor design began at the Laboratory in 1956 when Herbert MacPherson headed a team investigating the application of molten salt technology. The Laboratory's aircraft reactor experiments during the early 1950s used molten (fused) uranium fluorides (salts) as reactor fuel. Molten salt fuel could function at high temperatures at low pressures in a liquid system that could be cleansed of fission ashes without stopping the reactor. Like other liquid nuclear fuels, however, molten salts were highly corrosive and posed significant materials challenges. MacPherson's and Trauger's groups studied molten salt fuels and materials in the test loops built for the aircraft reactor project, conducted cost studies of molten salt reactors, and focused on identifying compatible corrosion-resistant materials for use in such reactors.

When an AEC task force in 1959 identified molten salt as the most promising of the liquid fuel reactor systems, the AEC approved a molten salt reactor experiment. By 1960, the Laboratory was designing an experimental molten salt reactor using graphite blocks as the moderator; a uranium or plutonium bearing fuel of molten fluorides circulated through metal tubes made of a nickel-molybdenum alloy, called Hastelloy N, developed earlier at the Laboratory for the aircraft reactor.

Molten salt reactor experiments continued at the Laboratory throughout the 1960s and into the early 1970s. Carlos Bamberger and colleagues devised a method of obtaining the element thorium by extracting it from the virtually inexhaustible supply of granite rocks found throughout the Earth's crust. When introduced into a nuclear reactor, the thorium is converted to fissionable uranium-233. The Laboratory's experimental molten salt reactor demonstrated its capability of using the thorium to uranium-233 fuel system in 1969.

PROJECT SHERWOOD

Alvin Weinberg described the Laboratory's use of the uranium-233 reactor fuel from thorium as "burning the rocks;" conversely, he called its secret investigations of producing fusion energy from heavy water (deuterium oxide), which could be obtained from sea water, as "burning the sea." Thus, by the late 1950s the Laboratory's olympians were searching for an inexhaustible energy supply extracted either from the Earth's crust or seas. Using elements found in abundance in granite rock or the sea would possibly provide limitless energy.

The Laboratory's fusion research efforts were no less promethean than its fission research. Such research began in Oak Ridge in 1953 as a small part of the AEC's classified Project Sherwood program. By the time of the second scientific olympics at Geneva in 1958, however, the Laboratory had become a world leader in fusion research.

Hydrogen nuclei release enormous energy when they fuse together, as in a thermonuclear reaction that the public commonly associates with the detonation of a hydrogen bomb. Fusion temperatures of the hydrogen isotopes deuterium and tritium (hydrogen 2 and 3) are about one million degrees Kelvin. Major research aimed at fusing these isotopes in a controlled thermonuclear reaction began in 1951, when Argentine President Juan Peron announced that scientists in his country had liberated energy through thermonuclear fusion without using uranium and under controlled conditions that could be replicated without causing a holocaust.

Peron's claim proved false, but it stimulated a host of international fusion research initiatives, including the AEC's classified Project Sherwood. Legend has it that the name Sherwood emanated from the answer to the question, "Would you like to have cheap, nonpolluting, and everlasting energy?" The answer was "Sure would (pronounced Sherwood)." In reality, the name was derived from a complicated pun on the Sherwood Forest legend, which involved robbing Hood Laboratory at the Massachusetts Institute of Technology to fund James Tuck's fusion research at Los Alamos.

To achieve fusion, scientists sought to contain a cloud, or plasma, of hydrogen ions at high temperature in a magnetic field. Because the plasma cooled if it touched the sides of its container, electromagnetic forces (pulling from different directions) were necessary to hold the plasma in the center away from the container's sides. If the plasma were suspended in the same place long enough and at temperatures high enough, scientists believed a fusion reaction would begin and eventually become self-sustaining.

In its early years, Project Sherwood centered around three fusion devices. Princeton University had a stellarator, a hollow twisted doughnut-shaped metal container, with electric wires coiled around it to supply a magnetic field and hold the charged hydrogen ions. Livermore Laboratory in California had a "mirror" device with a magnetic field stronger at its ends than in the middle to reflect hydrogen ions back to the middle of the field.

And James Tuck's Perhapsatron at Los Alamos sought to contain the hot plasma through a "magnetic pinch"—that is, magnetic forces were designed to hold, or pinch, the plasma toward the middle of the container.

In Oak Ridge, the Laboratory focused not on a particular device but on two problems basic to fusion devices: how to inject particles into the devices, and how to heat the plasma to temperatures high enough to ignite the reaction.

With large surplus electromagnets on-hand at Y-12 from the calutrons once used to separate uranium-235 from uranium-238, an ion source group in the Electronuclear Division--which included Ed Shipley, P.R. Bell, Al Simon, and John Luce--became responsible for fusion research. Their background in electromagnetic separation and high current cyclotrons led them to studies of energetic ion injection to create a hot plasma. Theoretical work showed promise and, in 1957, the Laboratory formed a Thermonuclear Experimental Division with a staff of seventy people to pursue the fusion challenge. Personnel came from the Physics and Electronuclear divisions and from the discontinued aircraft reactor project.

In 1957, published stories and unsubstantiated rumors hinted that British scientists might have achieved a successful fusion reaction. Although overstated, the stories and rumors nevertheless encouraged greater emphasis on fusion research by both the AEC and the Laboratory. Moving a particle accelerator into Y-12 to provide a beam of high energy deuterium molecular ions, Luce, Shipley, and their associates built the Direct Current Experiment (DCX), a magnetic mirror fusion device. In August 1957, they "crossed the swords," injecting a deuterium molecular beam to a carbon arc that dissociated the beam into a visible ring of circulating deuterium ions (shaped like a bicycle tire). This advance transformed Project Sherwood from a remote, abstract theory to a "real" possibility.

Planning for a second Geneva conference on peaceful uses of the atom coincided with the Laboratory's advance in fusion research. AEC Chairman Lewis Strauss, determined that the United States should achieve a triumph equal to that of 1955 at the 1958 scientific olympics, threw the AEC's full support behind fusion research. He hoped that American scientists could display an operating fusion energy device at the 1958 Geneva conference, just as they had displayed a successful nuclear reactor three years earlier.

"I have received a letter from Chairman Strauss exhorting the Laboratory to do everything it possibly can to have incontrovertible proof of a thermonuclear plasma by the time of Geneva," Weinberg informed Laboratory staff. He went on to say:

> We are now engaged in this enterprise; we have mobilized people from every part of the Laboratory for this purpose and, with complete assurance of unlimited support from the Commission, we have put the work into the very highest gear. I can think of few things that would give any of us as much satisfaction as to have Oak Ridge the scene of the first successful demonstration of substantial amounts of controlled thermonuclear energy.

1958 GENEVA CONFERENCE

By the time of the second Geneva conference on the peaceful uses of the atom in September 1958, intense media attention on the miracles of nuclear energy had jaded the public. Saturated for years with news about the potential miracles of nuclear energy, Americans turned their attention to other matters. Moreover, Soviet scientists, so prominent at the 1955 conference, were no longer subjects of great public curiosity.

As a result of this diminishing public interest, the second Geneva conference turned out to be less a media circus and more a conventional scientific convention. In 1958, only schemes and devices for achieving controlled thermonuclear reaction through fusion enjoyed the glamour linked to the first conference.

The second conference, however, was then the largest international scientific conference ever held. Exhibits filled a huge hall built on the grounds of the Palais des Nations. Sixty-one nations participated, and twenty-one exhibited fusion devices, fission reactors, atom smashers, or models of nuclear power plants.

The United States, Great Britain, and the Soviet Union declassified their fusion research at the time of the conference, and Chairman Lewis Strauss resigned from the AEC to lead the American delegation to Geneva. It took nearly ten hours to view the United States exhibit alone. The most popular attractions were models of the Laboratory's DCX fusion machine.

The Laboratory provided two full-scale working models of its DCX machine to display its operating principles. Through viewing windows, visitors could see the beam and ring of ions wound around it like a ball of yarn. Using a bit of showmanship, the Laboratory made the trapped ring visible by dusting tungsten particles onto it from above.

Soviet fusion specialists took intense interest in the DCX display because they were also pursuing a molecular-ion-injection approach to fusion. After the conference, other nations, drawing on the Laboratory's experience, built DCX-type machines, making them fundamental tools for plasma research.

Yet, optimism over the future success of fusion energy soon faded. The supposed British achievement of fusion with a pinch-type device proved premature, and the ability of pinch machines ever to provide a stable plasma was questioned. Unstable plasma escaping the magnetic field also plagued the Princeton stellarator and, by the end of 1958, Laboratory scientists learned that their carbon arc lost trapped ions, forcing the DCX staff to study different types of arcs and to plan an improved device, called DCX-2.

Alvin Weinberg, a proponent of nuclear fission and thorium breeding reactors, in 1959 compared Project Sherwood to "walking on planks over quicksand." Plasma physics was so novel then that solid spots remained unknown, nor was it fully apparent that any existed. "Working in this field requires a rugged constitution," Weinberg concluded, "but I'm told that those who can stand it find it stimulating."

Eugene Wigner reported that Soviet scientists were more cooperative at the 1958 Geneva conference than they had been in 1955, perhaps because of the successful launching of the Sputnik satellite into orbit in 1957. Wigner found them open about their nuclear fission and fusion energy research, but unwilling to share information about their space missions or their particle acceleration program. "Pure science in the Soviet Union still seems to be far from an open book," he observed.

Early Soviet achievements in space exploration sent shock waves throughout American political and scientific circles. Following the Soviet's successful launch of Sputnik, international scientific competition shifted from fission and fusion energy research to the race for space. As international scientific interests shifted, so did the focus of the federal government from the AEC to the new National Aeronautics and Space Administration (NASA). Nuclear research remained an important aspect of America's scientific agenda, but it now had to share the policy spotlight with space issues. Geneva conferences on the atom were held occasionally after 1958, but none ever gripped the public imagination as had the first and second.

AFTER THE GOLD

Nuclear reactor development at the Laboratory reached a pinnacle in 1956 and began a slow descent in 1957 with cancellation of its aircraft reactor program and troubles with its second experimental homogeneous reactor. In 1956, when the Laboratory budget was $60 million and its staff reached 4369, Weinberg boasted: "We are the largest nuclear energy laboratory in the United States, and we are among the half dozen largest technical institutions in the world."

With cancellation of the aircraft reactor in September 1957, the Laboratory budget was slashed twenty percent and its staffing cut to 3943. About 1500 personnel were at work on the aircraft reactor program, and the 1957 reduction would have been even steeper if the Laboratory had not absorbed some people into the molten salt reactor, gas cooled reactor, and Sherwood programs. Moreover, the Eisenhower administration froze the Laboratory's budget in 1957, forcing postponement of a major building expansion program that included an east wing of the general research building, an instruments building, and a metallurgy and ceramics building, which together would have added a half million square feet of work space. Weinberg called these "cataclysmic setbacks" that ranked with the loss of the materials testing reactor in 1947.

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HOMOGENEOUS REACTOR II

After successful operation of the first aqueous homogeneous reactor in 1954, the Laboratory proceeded with the design of a larger homogeneous reactor on a pilot plant scale. Whereas the first reactor had been a one-time experiment to prove yet unproven theoretical principles, the second reactor, sometimes identified as the Homogeneous Reactor Test (HRT), was designed to operate routinely for lengthy periods.

The second homogenous reactor was fueled by a uranyl sulfate solution containing ten grams of enriched uranium per kilogram of heavy water, which circulated through its core at the rate of 400 gallons per minute. Its fuel loop included the central core, a pressurizer, separator, steam generator, circulating pump, and interconnected piping. Its core vessel was made of zircaloy, which was approximately a yard in diameter and centered inside a sixty-inch spherical pressure vessel made of stainless steel. A reflector blanket of heavy water filled the space between the two vessels. Perhaps the most exotic nuclear reactor ever built, it gave Laboratory staffers trouble from the start.

First, during its shakedown run with pressurized water, chloride ions contaminated the leak detector lines, forcing the replacement of that system and delaying the power test by six months. In January 1958, the Laboratory found that bringing this reactor to critical mass without a control rod was a tricky proposition. (Weinberg called it a "rough and tough" business.) Problems with the reactor then developed where least expected.

The homogeneous reactor had run many megawatt hours from January into February 1958 when it became apparent that its outside stainless steel tank was corroding too rapidly. In April the reactor reached its design power of five megawatts, but a hole suddenly formed in the interior zircaloy tank. Viewing the hole through jerry-rigged periscope and mirrors, operators determined that the hole had been melted into the tank, meaning that uranium had settled out of the fuel solution and lodged on the tank's side where it melted the hole.

By the end of 1958, the AEC considered abandoning the homogeneous reactor, and Eugene Wigner came to the Laboratory to inspect it personally. "The trouble seems to be that the rich phase absorbs to the walls and forms a solid layer there," Wigner told AEC staff. He thought altering the flow of fluid through the core would provide a velocity needed to prevent settlement of the uranium on the tank walls. "It is my opinion that abandoning the program would be a monumental mistake," he warned, pointing out that the reactor could convert thorium into uranium-233 to supplement a dwindling supply of uranium-235.

The AEC allowed the Laboratory to alter the reactor flow and continue its testing in 1959. These activities were accomplished by interchanging the inlet and outlet to reverse the fluid flow through the reactor. Several lengthy test runs followed during 1959, and the reactor operated continuously for 105 days--at the time, a record for uninterrupted operation of reactors. The lengthy test run demonstrated the advantages of a homogeneous system, where new fuel could be added and fission products removed while the reactor continued to operate.

Near the end of the year, a second hole burned in the core tank. Laboratory staff again patched the hole through some difficult remote dentistry and started another test run. In view of these difficulties, Pennsylvania Power and Light Company and Westinghouse Corporation abandoned their proposal to build a homogenous reactor as a central power station.

During the shutdown and repairs, Congress viewed the aqueous homogeneous reactor troubles unfavorably and, in December 1960, the AEC directed the Laboratory to end testing and turn its attention to molten salt reactor and thorium breeder development. The last aqueous homogeneous reactor test run continued until early 1961. For months, the reactor operated at full power until a plug installed earlier to patch one of the uranium holes disintegrated.

ECOLOGICAL CHALLENGES

Even as the Laboratory climbed the acropolis of nuclear energy, challenges relating to nuclear fission and the Laboratory's missions arose. The threat of radioactive fallout from atmospheric testing of nuclear bombs and the need to deal more effectively with hazardous wastes called for research by the Laboratory's scientists. The need to broaden the Laboratory's base and avoid competition with private industry also challenged its management.

Until 1963, fission and fusion bomb tests were conducted in the atmosphere, causing deep public concern about radioactive fallout. A principal concern during the early 1950s was the fallout of strontium-90, a bone-seeking nuclide that fell from wind-blown clouds to Earth, where, for example, it could be sucked up by vegetation and eaten by cows to wind up in children's milk.

To study this and other issues of radiation ecology, the Laboratory, at the recommendation of Edward Struxness, hired Orlando Park, an ecologist from Northwestern University, as a consultant in 1953. The Laboratory subsequently asked Park's student, Stanley Auerbach, to join its Health Physics Division. Both Park and Auerbach were expert investigators of the effects of radioactivity on ecological systems, particularly how radioactive nuclides migrate from water and soil to plants, animals, and humans. A major issue in the early 1950s was how quickly strontium-90 in the soil was taken up by plants. In fact, this and other questions about radioactive fallout became issues in the 1956 presidential election. During the same year, the Laboratory expanded its scientific studies of radioactive fallout into a Radiation Ecology Section in the Health Physics Division under Auerbach.

Auerbach and his colleagues found a ready field laboratory for their work in the bed of White Oak Lake, a drained reservoir where the Laboratory once had flushed low-level wastes. Examining the native plants and even planting corn in the radioactive lakebed, the ecologists studied the manner in which vegetation absorbed nuclides from the environment. Investigations of insects, fish, mammals, and other creatures followed, enabling

Laboratory ecologists to establish international reputations in aquatic and terrestrial radioecology.

Taking advantage of the Laboratory's isotopes, the ecologists used radioactive tracers to follow the movements of animals, the route of chemicals through the food chain, and the rates of decomposition in forest detritus. Sponsoring national symposia on ecosystems and related subjects, their work added much to the study of radioecology, an emerging scientific field that counted Auerbach and his colleagues among its founders. When atmospheric bomb testing ended in 1963 and interest in fallout waned, the ecologists expanded their studies, forming the nucleus of the Environmental Sciences Division, established at the Laboratory in 1970.

The increasing number of nuclear reactors during the 1950s, both at the Laboratory and throughout the nation, produced increasing volumes of radioactive waste and growing concern about its disposal. In 1948, the Laboratory formed a Waste Disposal Research Section under sanitary engineer Roy Morton in the Health Physics Division and, in 1952, it completed a radioactive waste research laboratory building for waste management studies, supported by the AEC and the national civil defense agency.

During World War II, the Laboratory stored its radioactive wastes in underground tanks for later recovery of the uranium and released its low-level wastes untreated into White Oak Lake. To reduce the level of radioactivity entering White Oak Creek and eventually the Clinch River, the Laboratory built a waste treatment plant during the 1950s to remove strontium, rare earths, and other nuclides from its drainage. Uranium and other materials were recovered from underground tanks and remaining wastes pumped into disposal pits.

In 1953, the Laboratory initiated a multipronged remediation program designed to address its higher level waste disposal problems. The Chemical Technology Division devised a pot calcination strategy that heated high level liquid wastes in steel pots, converting the wastes into ceramic material for easier handling and storage. The Health Physics Division, under the direction of Edward Struxness and Wallace de Laguna, explored the hydrofracture disposal method used by the petroleum industry. The strategy called for drilling deep wells, applying pressure to fracture the rock substrata, and pumping cement grout mixed with radioactive wastes down the wells to spread into the rock and harden. Struxness also joined Frank Bruce of the Chemical Technology Division in studies of waste disposal in salt mines and, in 1959, the Laboratory tested this method by storing nonradioactive wastes in a Kansas salt mine. These methods seemed promising during the 1950s, but each presented difficulties and none permanently resolved the disposal challenges.

As the Laboratory's operating nuclear reactors increased in number and its fuel processing program burgeoned, the safety of equipment and the health of its personnel became a growing concern. Such concerns came to the forefront after a serious nuclear mishap in England during the late 1950s.

Windscale?

At Windscale, England, a British graphite reactor caught fire in 1957 when its operators attempted to anneal it to release the energy stored in the graphite as a result of the "Wigner disease." (Annealing is a process of heating and slow cooling designed to increase a material's toughness and reduce its brittleness.) Herbert MacPherson and a Laboratory team visited Windscale to review the accident and consider its implications for operation of the Laboratory's own graphite reactor. MacPherson reported the Laboratory's reactor operated at lower power and higher temperature than the Windscale reactor and a similar accident could not occur in Oak Ridge. In the early 1960s, the Laboratory's graphite reactor was annealed three times without difficulties by reversing its air flow and slowly raising power.

Although no accidents involving reactors occurred at the Laboratory, in 1959 three threatening situations involving radioactive materials did take place. First, fission products accidentally entered the liquid waste disposal system from the THOREX pilot plant and were trapped in a settling basin. Second, ruthenium oxide trapped on the brick smokestack's rusty ductwork shook loose during maintenance, forcing the installation of more filters and scrubbers in the stack. And, third, a chemical explosion in the THOREX pilot plant during decontamination released about six-tenths of a gram of plutonium from a hot cell, spreading it onto a street and the graphite reactor next to the plant.

FP → LIQ. WASTE SYSTEM

Ru OXIDE shook loose in stack

Chem. explosion in THOREX plant

It was largely chance that no personnel suffered overexposure from these accidents, and the Laboratory immediately stopped its radiochemical operations for safety review. Improved containment measures followed, and Frank Bruce took charge of the Laboratory's radiation safety and control office to implement stricter safety precautions. P.R. Bell, Cas Borkowski, and colleagues also devised ingenious compact radiation monitors. One called the pocket screamer was worn in the pocket and chirped and flashed at a speed proportional to gamma dosage rate. These devices were supplied to Laboratory personnel.

In addition to these challenges, the Laboratory found it increasingly difficult to keep background radiation at acceptable levels because the amount of radioactivity handled by the Laboratory increased during the 1950s, while government regulators steadily reduced the permissible levels to which workers could be exposed. Karl Morgan at the Laboratory and other health physicists maintained that the maximum permissible levels should be so low that hazards resulting from radiation were no greater than other normal occupational hazards. Laboratory biologists, however, had obtained differing results in studies of the effects of background radiation. Arthur Upton, for example, found that mice subjected to low-level chronic radiation seemed to have an improved survival rate from infections or other biological crises.

COMPETITIVE CHALLENGES

Not only did the Laboratory face international competition during the late 1950s, it increasingly encountered competition at home from the private sector nuclear industry. By 1959, the rapidly growing nuclear industry questioned the role of national laboratories, urging that some of their work be contracted to private industry or even that the laboratories be closed. Partly as a result of these pressures, the AEC circumscribed Laboratory programs in the late 1950s. For example, the AEC canceled the power reactor fuel reprocessing facility that the Chemical Technology Division hoped to build in Oak Ridge. In 1959, the Laboratory also recognized that it would soon lose its homogeneous and gas cooled reactor programs.

In response to the expected decline in its nuclear reactor and chemical reprocessing programs, the Laboratory conducted an advanced technologies seminar in 1959 to identify possible missions beyond nuclear energy. The seminar recommended additional study of nationally valuable research programs that had not been commercially exploited. Desalination of sea water, weather science, oceanography, space technology, chemical contamination, and large-scale biology were mentioned as potential broad avenues of inquiry.

While convinced that federal investment in national laboratories was too great to permit their abandonment, Weinberg recognized that a realignment of their missions was in order. Asked to forecast the role of science and national laboratories during the 1960s, Weinberg expressed his hope that they "will be able to move more strongly toward those issues, primarily in the biological sciences, which bear directly upon the welfare of mankind."

The Olympics of antiquity had begun as a single event: a long distance race between the best runners of competing Greek city-states. The modern Olympics, particularly in the post-World War II era, have been transformed into a carnival of sporting events in which athletes worldwide display their diverse athletic skills as runners, swimmers, equestrians, weight lifters, skeet shooter, and volley and basketball players.

In the same way, the scientific olympics in which the Laboratory competed began as a contest measuring the scientific prowess of the Soviet Union and the United States. The Laboratory, as one of America's primary institutions for scientific research, had a simple goal: display the nation's scientific talent and accomplishments in the most dramatic way possible.

As the 1950s unfolded, however, the contest became more diverse and complicated. Space issues eclipsed the importance of nuclear research as the most important symbol of a nation's scientific capabilities; other goals began to compete for the Laboratory's resources and energies; and the initial successes of fission and fusion research proved difficult to replicate. In short, like Olympic runners who followed in the path of their earliest brethren, Laboratory scientists by the end of the 1950s found they would have to share the arena with other figures and other events. As the Laboratory entered the 1960s, its work would be less dramatic but no less important, and its focus more diverse but no less compelling.

CHAPTER V

THE BALANCED LABORATORY

In 1961, Director Alvin Weinberg predicted historians would view atom-smashing accelerators, fission reactors, and fusion energy machines as prime symbols of modern history, just as the Egyptian pyramids and Roman Coliseum have come to symbolize those ancient cultures. The same year that Weinberg made that prediction, however, Laboratory activities began to shift slowly from a reliance on the traditional sciences and engineering hardware to the softer sciences related to social engineering and environmental restoration.

In the 1960s, when congressional committees called on the Atomic Energy Commission (AEC) to expand and diversify national laboratory programs in order to create more "balanced laboratories," the call struck a responsive chord in Oak Ridge. Program disruptions that followed the terminations of the materials test reactor in 1947, the aircraft nuclear reactor in 1957, and the homogeneous reactor test in 1961 taught Laboratory management the dangers of relying on a few large hardware programs. In addition, national participation in the space race heated up the competition for federal research dollars.

Responding to the "balanced laboratory" challenge, Director Weinberg organized an advanced technologies seminar to consider the Laboratory's future. "What we should try to do is to identify long-range, valid missions which in scope and importance are suitable for prosecution by ORNL," he said. "Most missions of this sort will probably not fall in the field of nuclear energy," Weinberg added. "This need not bother us since in the very long run," he predicted, "ORNL very possibly will not be in nuclear energy exclusively."

As a member of science panels advising Presidents Dwight Eisenhower and John Kennedy, Weinberg aggressively sought to use Laboratory expertise to help solve national and international environmental and social problems. Under Weinberg's leadership, and the leadership of Alexander Hollaender in biology, the Laboratory broadened its programs during the 1960s. Although basic nuclear science continued as a mainstay, the Laboratory increasingly focused on the applications and safety of nuclear energy: how commercial nuclear power could reduce air pollution and chemical contamination resulting from burning fossil fuels, and produce fresh water from the seas for agricultural and industrial purposes.

The Laboratory had been a nuclear science center from its inception; in 1961, it took the first steps toward becoming a national laboratory in a broader sense. Before 1961, all Laboratory funding came from the AEC. A decade later, about fourteen percent of its $100 million annual budget came from agencies outside the AEC, usually for programs connected with civil defense, desalination, space travel, and cancer research.

INFORMATION CENTERS

An immediate local result of Weinberg's service on a presidential science panel was the implementation of programs to manage the scientific "information revolution." A historian in 1961 pointed out that the first science journal was published in 1665; the number climbed to 100 in 1800, 10,000 in 1900, and 40,000 by 1961. Science was suffering under a blizzard of new publications. This information explosion, atop increasing specialization and a threatened shortage of scientists, the historian predicted, could cause the collapse of science by 1970. Placed in charge of a presidential task force investigating this ominous trend, Weinberg echoed the historian's sentiments when he said scientists were "being snowed by a mound of undigested reports, papers, meetings, and books."

To help solve this crisis, Weinberg proposed the creation of information centers. Rather than traditional libraries with stacks of books and shelves of journals available to researchers, these centers would consist of scientists who would read everything published in their specialty, review the data, and provide their colleagues with abstracts, critical reviews, and bibliographic tools. These scientific "middlemen" would contribute to science directly by perceiving new relationships during their in-depth reviews of the literature and applying their new perceptions to their own research.

Weinberg's recommendation received broad acceptance. Nationally, more than 300 science information centers were formed, including a dozen at the Laboratory. Among the places designated as a Laboratory center was the nuclear data project, begun at the Laboratory in the late 1940s by Kay Way. In 1949, Way moved the nuclear data project to Washington, D.C., under sponsorship of the Bureau of Standards and later the National Academy of Science. Weinberg brought Way and her team of seven physicists back to the Laboratory in 1964, where they continued the systematic collection and evaluation of nuclear data, publishing it in tabulated form for use by researchers. Other Laboratory information centers specialized in the fields of accelerators, atomic-collision cross sections, charged particles, engineering data, isotopes, nuclear safety, neutron cross sections, materials research, shielding, and environmental and life sciences. Coordinated by Walter Jordan and Francois Kertesz, the centers disseminated the information they collected largely by publishing review journals, annotated bibliographies, charts, and digital computer codes. Widely acclaimed, many of these publications continued to inform scientists into the 1990s.

DESALTING THE SEAS

Although less successful in the long run than the information centers, the Laboratory's research into desalting sea water attracted the most public and political attention of all its endeavors to achieve "balance." The program had two distinct points of origin.

As a result of its research into fluid fuel reactors and the chemical processing of nuclear fuels, the Laboratory hired some of the world's foremost solution chemists. Some of these chemists had become intrigued by the chemistry of desalting sea water. They voiced support for desalination as a new Laboratory mission in Weinberg's advanced technology seminars, and a committee headed by Richard Lyon explored the mission with the Office of Saline Water, a research arm of the Department of the Interior.

In Washington, D.C., Weinberg discussed desalination as a possible mission for the Laboratory with other members of the presidential science panel, especially Secretary of the Interior Stuart Udall's science advisor. Managers at Interior's Office of Saline Water lacked enthusiasm for funding desalting research at the Laboratory, but Udall and Glenn Seaborg, chairman of the AEC, orchestrated a "shotgun wedding" between the two federal agencies.

Funded initially at $600,000 per year by the Office of Saline Water and the AEC, a team of twenty solution chemists and engineers led by Kurt Kraus, an expert on the chemistry of heavy elements, investigated the physical chemistry of sea water, focusing eventually on hyperfiltration (reverse osmosis) to remove salts and contaminants from water. Development of dynamic membranes for rapid production of fresh water from the seas earned the team wide recognition.

A second component of the Laboratory's desalting work originated with Philip Hammond, brought to the Laboratory from

Los Alamos Laboratory in 1961. Hammond's maxim was "bigger is cheaper." He contended that large nuclear reactors could produce power and heat cheaply enough to desalt sea water, providing fresh water for agriculture and electric power for industry. Although skeptical at first, Laboratory management eventually found Hammond's concept to have merit, a belief also expressed by an independent task force of the Department of the Interior.

Presidents John Kennedy and Lyndon Johnson judged desalination to be in the national interest. Johnson, in fact, sought to make it an instrument of foreign policy, hoping to build nuclear desalination centers in arid regions, such as the Middle East, to reduce international competition for natural resources. Echoing the president, Weinberg said, "I can think of few major technical achievements, including manned exploration of space, that would have as much beneficial political impact as would making the deserts bloom with nuclear energy."

At the 1964 United Nations conference on peaceful uses of the atom in Geneva, President Johnson, Soviet Premier Nikita Khruschev, and United Nations Secretary-General U Thant viewed the Laboratory's proposed nuclear agro-industrial complexes favorably. Dubbed "nuplexes" by the media, these blueprints called for huge nuclear reactors to produce fresh water from the ocean for irrigating crops and for generating electric power for industry.

With international support, Laboratory staff in 1964 started travels to Israel, India, Puerto Rico, Pakistan, Mexico, and the

Soviet Union to assist with plans for desalination plants. In California, water-starved Los Angeles laid plans to build a large desalination nuplex on an island off the coast. In private, however, Weinberg warned the AEC's Seaborg that desalination publicity had outrun the technical capabilities, and the Laboratory needed increased research funding "so that the technical basis for the politicians' speeches always remains as firm as possible."

By 1965, when President Johnson announced his "Water for Peace" program, the Laboratory had a hundred scientists studying desalination. Its water research team was developing evaporator tubes four times more efficient at producing fresh water from the sea than earlier models. In addition, the Rockefeller Foundation, which funded research into disease- and drought-resistant seedlings to nurture the Green Revolution, became interested in nuplexes as potential food factories in poverty-stricken nations. Former President Eisenhower and former AEC chairman Strauss endorsed a desalination plant in the Middle East sponsored by private funds funneled through the International Atomic Energy Agency.

"In one sense it is premature to try to define the future role of nuclear desalinization for agriculture, when no large city supply plant is yet operating," warned Philip Hammond in 1966. "So far one plant is under construction (in the Soviet Union), the Israeli plant has been found feasible, and the MWD station (in Los Angeles) has reached the final stages of negotiation. These pioneer plants are essential steps in development of a brand new resource."

The desalination bubble burst as quickly as it had formed. In 1968, Los Angeles abandoned its plans for a 150 million gallon per day nuclear desalination plant. The costs of nuclear plants had escalated so rapidly that the plant no longer seemed economically feasible. As nuclear power costs skyrocketed and the country's social and environmental concerns moved to the forefront, the media and political leaders lost interest in nuplexes. None was ever built, and funding for desalination research dried up.

"Solving today's social and economic problems with tomorrow's technology is risky," Weinberg lamented near the close of this Laboratory effort to become more "balanced." Yet, the information obtained from desalination research later proved valuable for Laboratory development of technologies to treat contaminated water and sewage.

BIG BIOLOGY

Alexander Hollaender's Biology Division prospered enormously during the Laboratory's efforts to "balance" its research programs. Staffed by experts who studied the genetic and physical effects of radiation on living organisms, the division also hoped to shed light on radiation's impact on the environment.

When Rachel Carson's *Silent Spring* was published in 1962, it stimulated intense public concern about the role chemical agents might play in biological and environmental degradation. This widespread worry prompted increased research funding for the National Institutes of Health (NIH), whose managers soon received visits from Hollaender, Weinberg, and other Laboratory staff. The discussions--and subsequent funding--bore fruit during the 1960s in increased biological understanding and improved tools for science and medicine.

With support from the National Cancer Institute, the Biology Division opened a Biophysical Separations Laboratory, taking advantage of centrifuge designs by Paul Vanstrum and fellow researchers at the K-25 plant. The K-25 team had devised improved centrifuges for the separation of uranium isotopes, and in 1961 a biology team headed by Norman Anderson, with advice from Jonas Salk of polio vaccine fame, adopted centrifuge technology to separate viruses from human leukemic plasma, hoping to identify a cure for leukemia. This striking use of nuclear separations technology to advance science and medical research led in several directions.

A hollow cylinder subdivided into sectors, which created a zonal centrifuge whirling at high speeds, could separate substances at the molecular level into their constituents according to size and density. Anderson and his team experimented with centrifuges whirling up to 141,000 revolutions per minute. They learned the machines could separate impurities from the viruses causing polio and the Hong Kong flu. This finding had practical applications in large-scale separations required to produce vaccines against such diseases. By cleansing vaccines of foreign proteins, the zonal centrifuge could minimize the fever reactions that often accompanied immunizations. By the late 1960s, millions of people received vaccines that had been purified in zonal centrifuges, which also provided pure rabies vaccine for their pets.

In other applications jointly sponsored by the AEC and NIH, the Molecular Anatomy Program (MAN) managed by Norman Anderson sought to identify the metabolic profiles and chemical characteristics of all cell constituents. Charles Scott and associates in the MAN program devised portable centrifugal analyzers later commonly used in medical clinics across the nation. Spinning at high speeds, these analyzers could separate and assay components of blood, urine, and other body fluids in minutes, recording the data on computers for medical diagnosis. The best known of these machines was the Laboratory's GeMSAEC, so named because its development was funded jointly by the NIH's General Medical Sciences division and the AEC. Using a rotor spinning fifteen transparent tubes past a light beam, GeMSAEC displayed the results on an oscilloscope and fed the data into a computer, completing fifteen medical analyses in the time it previously took to perform one analysis.

Another eye-catching development in the Biology Division emanated from the Laboratory's search for powerful microscopes able to view and photograph objects the size of a few atoms. After the Laboratory built an experimental microscope with high resolution in 1967, Oscar Miller and Barbara Beatty of the Biology Division placed frog eggs under the microscope and photographed genes in the act of making RNA. "I never expected to see the thread of life, the mysterious stuff that poets conjured long ago to explain the passage of the heartbeat from generation to generation across the eons," mused John Lear of *Saturday Review of Literature*, who came from New York to peep into the microscope. "Yet today the thread lies clearly visible before me, under the lens of an electron microscope, here in the Tennessee hills."

In addition to funding from the NIH for centrifuge and microscope research, the Biology Division received support in 1965 from the National Cancer Institute for a Co-Carcinogenesis Research Laboratory to investigate the complex biochemical events leading to cancer growth. This work took advantage of the nearly a quarter million mice on hand at the Biology Division at the Y-12 complex. Arthur Upton and his associates used the mice to study the physical effects of radiation and chemical agents on the environment and on human life. The experiments largely concerned airborne carcinogenesis, or the induction of lung cancer by exposure to pesticides, sulfur dioxide, city smog, or cigarette smoke, both singly and together. Mice exposed to these irritants in an inhalation chamber were then raised in a clean environment while scientists observed the formation of tumors. Upton later left the Laboratory to become director of the National Cancer Institute.

At the time, the components of cigarette smoke were largely unknown. To overcome this handicap, a Lung Cancer Task Force from the Analytical Chemistry Division became involved in carcinogenesis studies when they devised "ORNL Smoking Machine, Model Number 1." It smoked six cigarettes at a time, even mimicking human drags on the weed. "This isn't an easy task by any means," commented Herman Holsopple, who built the machine. "Every component in cigarette smoke must first be identified and then studied for its biological effect on humans, and right now we're just trying to identify some of the components."

To determine how environmental hazards threaten human health required big protocols, large epidemiologic studies, and expensive machines--just the requirements that Big Biology at the Laboratory could provide. By the end of the 1960s, the Biology Division, employing 450 personnel, had become the largest division in the Laboratory. Although it lost a driving force with the retirement of Alexander Hollaender in 1966, the Biology Division remained at the cutting edge of biological hazards research into the 1990s.

Medical knowledge and clinical machines developed at the Laboratory with NIH funding stimulated the formation of a University of Tennessee/Oak Ridge National Laboratory Graduate

School of Biomedical Science. Thanks to grants from the Ford Foundation, the Laboratory had entered a cooperative program with the University of Tennessee during the early 1960s. Under the Ford Foundation program, as many as fifty Laboratory scientists worked several days each week as Laboratory researchers and spent the remainder of the week as a member of the university science faculty.

This cooperation laid the groundwork for a challenge presented in 1965 by James Shannon, director of NIH. Shannon planned a graduate school in biomedical science near NIH headquarters at Bethesda, Maryland, and as a condition for expanding NIH programs at the Laboratory, he urged the creation of a similar graduate school in Oak Ridge.

After Weinberg, Clarence Larson, and James Liverman obtained approval for such a school from the AEC commissioners and Donald Hornig, President Johnson's science advisor, Weinberg asked Andrew Holt, president of the University of Tennessee, if he would be interested in developing the school cooperatively. "Our location in Appalachia and the strong contribution which a major new biomedical program would make to President Johnson's Great Society," Weinberg told Holt, "should enlist the aid of our U.S. Senators and Congressmen as well as the President."

President Holt and university trustees approved the school in late 1965. Governor Frank Clement contributed $100,000 of state funds, and Clarence Larson arranged a $100,000 contribution from Union Carbide. In 1967, the UT-ORNL Graduate School of

Biomedical Science opened, and Clinton Fuller was its first director. It was staffed chiefly by Biology Division personnel holding joint appointments with the University of Tennessee and the Laboratory.

CIVIL DEFENSE

At the same time the Graduate School of Biomedical Science was being organized, Weinberg explored the formation of a Civil Defense Institute at Oak Ridge. The origins of this concept may be traced to the closing ceremony for the Laboratory's historic graphite reactor in November 1963.

AEC chairman Seaborg, Eugene Wigner, Richard Doan, and other alumni of the Laboratory's wartime campaign returned to Oak Ridge for a nostalgic ceremony formally deactivating the graphite reactor on November 4, 1963, after twenty years of service. The next morning, Wigner learned that he would receive the Nobel prize for physics, an award adding to his public visibility and prominence. At the time, he was campaigning for improved national civil defense. "According to the preamble to the Constitution, one of the purposes of the Union was to provide for the common defense," said Wigner. "It seems difficult to think of defense without making every effort toward protecting what is most important: the lives of the people."

When the graphite reactor ceased operation in 1963, confrontations between President Kennedy and Soviet Premier

Khruschev over Berlin and Cuba had spurred major funding for civil defense in the United States. Wigner met with the director of the Office of Civil Defense to propose use of the Laboratory's talents in ecology, shielding, and radiation detection for civil defense research, and he spent the summer of 1963 leading a Defense Department seminar on civil defense problems.

Anxious to bring his old friend, the Nobel laureate, back to the Laboratory, Weinberg broached a civil defense mission for Oak Ridge with the AEC. He knew the AEC staff had cooperated for years with civil defense officials and had approved civil defense research funded by the Defense Department. The AEC staff warned him, however, that the Laboratory could not become involved in selling the politically controversial civil defense program to the public.

With funding from the Office of Civil Defense assured, Wigner returned from Princeton University to the Laboratory in September 1964 for his third extended stay. He headed a staff of twenty, who operated on the premise that improved civil defense might reduce rather than increase the probability of nuclear war. Although outsiders disagreed, Wigner's group contended that civil defense could bolster disarmament negotiations because nations that had adequate civil defense could blunt the force of imprudent adventures.

The Laboratory's civil defense research initially focused on underground tunnels to protect urban populations, and on related issues on how to rid the tunnels of body heat, protect against firestorms and blasts, and provide them with power, air, and other utilities. The researchers devised some ingenious solutions, such as storing blocks of ice underground to absorb body heat and supply water. From this base, their research expanded to include underground highways, subway systems, and parking garages as part of a protective system.

Designing such systems required demographic knowledge, such as the number and probable age distribution of the people to be protected. To uncover this information, the Laboratory hired demographers Everett Lee and William Pendleton and joined Oak Ridge Associated Universities in sponsoring the formation of the Southern Regional Demographic group in 1970.

The research also required understanding of the reactions of people under the stresses that would accompany an emergency use of underground shelters. To explore this problem, the Laboratory hired its first social scientists, including Davis and Susan Bobrow and Claire Nader, the sister of Ralph Nader.

Years before gaining fame as a consumer advocate, Ralph Nader came to the Laboratory to write about its activities. Noting that Oak Ridge had not then attracted many technology firms such as those clustered near Boston and San Francisco, Nader asked whether its rural isolation was the culprit. "What the city-based people call our isolation, we call our freedom," responded an Oak Ridge physicist, "freedom from the congestion and implosion of the metropolis and freedom to match these beautiful natural environments between the Cumberlands and the Smokies with the finest possible work of our minds and hands."

The potential effects of nuclear fallout on this natural environment became a major concern of Stanley Auerbach and his radioecology scientists. Auerbach had attended early civil defense conferences with Wigner because of public concerns about the ecological consequences of a nuclear war. As one result, in 1967, small plots of land at the Laboratory were treated with cesium-137 coated particles of weapons fallout size to observe their environmental effects. This proved to be the last large-scale application of radionuclides to test for field effects at the Laboratory, although radiotracer studies continued in previously contaminated sites.

CS-137 PLOTS

After a year of setting the foundation for civil defense research, Eugene Wigner passed again through his revolving door back to Princeton University, promising to return regularly for additional defense consultations. James Bresee, and later Conrad Chester, succeeded Wigner as chief of the Laboratory's civil defense research and, with added funding from the Department of Housing and Urban Development, explored multipurpose utility service tunnels, nuclear energy centers for cities, management of urban wastes, and a variety of other municipal problems.

Among the accomplishments of the civil defense staff were Joanne Gailar's analysis of Soviet civil defense plans in 1969, which encouraged civilian evacuation planning in the United States to counter Soviet planning, and Cresson Kearny's field manual for survival skills and expedient shelters. Because underground shelters were energy efficient, Kearny's manual subsequently enjoyed wide distribution. Studies examining the preservation of emergency food supplies and the needs for alternative energy sources, in fact, eventually brought the civil defense group an assignment to analyze solar energy.

During the late 1960s, Weinberg explored with the University of Tennessee and state officials the formation of a Civil Defense Institute in Oak Ridge, similar to the Space Science Institute established at Tullahoma, Tennessee. This effort proved unfruitful, but the Laboratory's studies of emergency technology continued, concentrating by 1990 on evacuation and sheltering from chemical hazards. At the outbreak of the 1991 Gulf War, military authorities thought it important that Conrad Chester dust off the Laboratory's old civil defense reports on biological weapons.

THE LAB IN SPACE

Alvin Weinberg in 1961 had concerns about the prospects of "scientific olympics" with the Soviets that focused on launching manned spacecraft. He thought the space race had little connection with the well-being of people, and he worried about shielding spacecraft crews against solar radiation. The National Aeronautics and Space Administration (NASA) responded by funding Laboratory studies of radiation shielding and the biological effects of solar radiation. NASA also partially funded the AEC Systems for Nuclear Auxiliary Power for long-distance space exploration. The space race brought $3 million into the Laboratory budget in 1962 and, by 1966, the Laboratory had 160 personnel in ten different divisions participating in the space olympics.

The Biology, Health Physics, and Neutron Physics divisions received assignments to assay the biological effects of radiation from the Van Allen belt and solar flares and to devise lightweight shields to protect crews of the Apollo spacecraft. In addition to ground research, the Biology Division sent boxes containing bacteria and radioactive phosphorus aboard Gemini 3 and 11 and also placed blood samples aboard biosatellites to assess radiobiological effects in space. The Health Physics Division exposed small animals and plastic phantoms resembling humans to fast-burst radiation, thereby estimating the radiation dosages to internal organs that might await the Apollo crews. Fred Maienschein, Charles Clifford, and the Neutron Physics Division used the tower shielding facility and linear accelerators to design lightweight shielding for the Apollo spacecraft.

The AEC Systems for Nuclear Auxiliary Power program, begun in 1956, aimed to design compact, maintenance-free power generators for use in remote locations at sea, on land, and in space. Under AEC assignment, the Laboratory undertook studies of two types of generators: miniature nuclear reactors and radioisotope generators.

Arthur Fraas led a team studying a small reactor using molten potassium to spin a turbine generating electricity for use in airless, weightless environments. Although not adopted by the AEC for space missions, its boiling potassium technology interested scientists for other applications.

The Isotopes Division received a major assignment from the AEC to produce massive blocks and pellets of radioactive isotopes, which became incandescently hot as they decayed and provided power for thermoelectric generators. Most of these isotopes went into portable power generators built by the Martin Marietta Corporation to supply power to weather stations in the Arctic and to Navy navigation buoys and beacons at sea. Because deep space exploration required too many panels for the use of solar energy in the spacecraft, some of the tiny space probes launched toward the outer planets of the solar system during the 1970s used the Peltier effect from radioisotopic heat to produce electricity for as long as thirty years without fuel replenishment. These survey craft returned spectacular pictures of the outer planets back to Earth a decade or more later.

As planning for NASA missions to the moon began, the Laboratory lost personnel to NASA, including P.R. Bell, who, as director of NASA's Lunar Receiving Laboratory in Houston, requested assistance from his friends in Oak Ridge. Neil Armstrong in July 1969 and other astronauts who later landed on the moon carried telescoping scoops for collecting moon rocks designed by Union Carbide's General Engineering Division and fabricated by the Plant and Equipment Division in Oak Ridge. Richard Fox of the Laboratory's Instrumentation and Controls Division--one of the veterans of the 1942 Fermi experiments in Chicago--designed the vacuum-sealed boxes that housed lunar rock samples after their return to Earth; some of those samples came to the Laboratory for intensive study.

Although less than four percent of the Laboratory's budget came from NASA programs, the personnel involved took pride in helping win the space race. In reflecting on the Laboratory's work for NASA at the end of the 1960s, Weinberg observed that its scientific aspects had been challenging and its management even more so. NASA and other non-AEC projects, however, were subject to micromanagement by the agencies providing the funding. And the Laboratory missed the budgetary flexibility that AEC-funded programs allowed.

ENVIRONMENT

Because the AEC had no firm policy on performing work for other agencies, the Laboratory during the 1960s approached each external effort *ad hoc*, gaining approval from AEC headquarters for each new venture. By 1969, fourteen percent of the Laboratory's programs consisted of nonnuclear work for agencies other than the AEC. Argonne, Brookhaven, and other laboratories then had less than one percent of their work funded outside the AEC.

In 1967, Congress amended the Atomic Energy Act to further encourage work for other agencies by AEC laboratories. The AEC, along with Congressman Chet Holifield of the Joint Committee on Atomic Energy, urged the laboratories to initiate studies of environmental pollution, then an increasingly popular and well-funded program under the Federal Water Pollution Control Agency. Weinberg advised the AEC's general manager that Auerbach's ecological studies and Kraus's water research placed the Laboratory in a strategic position to attack water pollution by identifying water pollutants and assessing their effects on aquatic and terrestrial life. Technology developed during the desalination studies could be adapted to improve sewage wastewater treatment. Moreover, Laboratory capabilities in analytical chemistry could be applied to investigations of atmospheric pollution, and biologists could expand their analysis of the effects of chemical agents on living organisms.

The Federal Water Pollution Control Agency did not accept the Laboratory's first proposal in 1967 to investigate stream eutrophication and its relationship to agricultural land management. Auerbach and his ecologists then proposed to the AEC that it approve Laboratory study of the impacts of heated water released from power plant cooling facilities into aquatic systems together with construction of an aquatic ecology research laboratory. When the AEC approved this initiative, Auerbach recruited Charles Coutant, experienced in aquatic thermal effects research, to lead this research effort at the Laboratory.

For environmental research at the Laboratory, 1967 was literally and figuratively a watershed year. It was the year the AEC approved Daniel Nelson and James Curlin's proposed development of the Walker Branch Watershed research facility, a small stream basin near the main Laboratory complex, as an experimental center for studies of relations between terrestrial and aquatic ecosystems. With concrete weirs and gauges for precise measurements of streamflows, the Walker Branch facility, Auerbach later recalled, marked the beginning of educating Laboratory operating and engineering personnel about the requirements of large-scale environmental research for sophisticated devices and instrumentation.

In 1967 as well, the National Science Foundation appointed Auerbach director of the ecosystems component of an International Biome Program for the eastern United States. Funded at about $1 million annually for eight years, this program, Auerbach asserts, was the first major funding by the National Science Foundation of work at an AEC laboratory.

As the 1960s waned, national concerns about ecological damages and pollution threats made themselves felt. As this environmental movement fermented, the Laboratory's potential as a center for research relating to the problems received increasing recognition. Auerbach, biologist William Russell, and other Laboratory ecological and life scientists went on the road to public hearings where they found the people jittery about the environmental and health impacts of nuclear energy. Although spearheading investigations of environmental pollution, the Laboratory, along with the AEC and the nuclear industry, found itself increasingly on the defensive against charges leveled by environmental activists. Questions concerning the safety of nuclear reactors became increasingly pertinent to Laboratory research programs.

NUCLEAR SAFETY

By the end of the 1960s, twenty percent of the Laboratory's reactor budget was devoted to nuclear safety. The Laboratory had a nuclear safety pilot plant operating to test fission-product release and fuel transport; it was developing a mock-up facility to test fast breeder reactor fuel bundles and a heat-transfer facility to test fuel element behavior in the event of coolant-loss accidents. It also was devising filters to contain radioactive iodine that might be released during accidents, and had staff participating in the design of auxiliary cooling systems for reactors to prevent meltdowns.

The Laboratory's Heavy Section Steel program, under Joel Witt and Graydon Whitman, was closely examining reactor pressure vessels to ascertain their performance under various stresses. Early steel pressure vessels in reactors had ranged from three- to ten-inches thick, but the larger vessels designed by 1968 were as much as fourteen inches thick. The Heavy Section Steel program's task was to investigate this armor-like steel and devise safety codes and standards for its use in reactor vessels.

Although private nuclear industry shared the costs of heavy section steel investigations and other nuclear safety programs with the AEC, these studies were not considered work for other agencies; nor did they foreshadow a Laboratory role in environmental science. To address possible future roles, the Laboratory obtained National Science Foundation funding for summer seminars during the late 1960s. These seminars began in 1967 with a multidisciplinary study of a nuclear agro-industrial complex and expanded in 1968 to include Laboratory, Tennessee Valley Authority, and university scientists and engineers investigating the resources of the Middle East and the health and education of the Middle Eastern population. Milton Edlund and James Lane headed the Middle East studies for the Laboratory and visited this far away region to explore potential developments there.

In the summers of 1969 and 1970, seminars organized by David Rose, who came to the Laboratory from MIT, and by Laboratory staff members John Gibbons, Claire Nader, and James Liverman, addressed environmental issues and the general role of science in the formation of public policy. In retrospect, these far-ranging seminars were pivotal events in the formation of the Laboratory's Environmental Sciences Division and Energy Division, which employs many of the Laboratory's social scientists. Out of these seminars grew a proposal to create national environmental laboratories, or at least one in Oak Ridge.

Declaring that "ecologists have displaced the physicists and the economists as high priests in this new era of environmental concern," Weinberg formed a National Environmental Concept Committee under David Rose. The committee produced a report entitled, *The Case for National Environmental Laboratories*, and delivered a copy to Senator Howard Baker of Tennessee, who had it printed as a congressional document. Then Weinberg and Rose met with Senators Baker and Edmund Muskie to discuss it. In early 1970, a House committee added $4 million to the National Science Foundation budget earmarked for studies at the Laboratory of sewage hyperfiltration, air pollution, waste management, and drug and chemical toxicity, and Senators Baker and Muskie sponsored a resolution establishing a National Environmental Laboratory at Oak Ridge. Momentarily, it appeared that the Laboratory might jump into the forefront of environmental science.

Congressman Chet Holifield of the Joint Committee on Atomic Energy surprised the Laboratory's staff when he blasted the Baker-Muskie resolution. Rumor had it that he said, "Let Muskie get his own laboratories!" Holifield added a rider to the 1970 AEC authorization that read:

> The Joint Committee sees signs that ambition to acquire new knowledge and expertise in fields outside the present competence and mission of an AEC National Laboratory, in order to attain and provide wisdom which this country needs in connection with non-nuclear environmental and ecological problems, is spurring at least one laboratory to solicit activities unrelated to

> its atomic energy programs and for which it does not now have special competence or talents.

Thus chastised, Oak Ridge saw its chances of becoming the National Environmental Laboratory fade. Nevertheless, with enactment of the National Environmental Policy Act of 1970 and formation of the Environmental Protection Agency, the Laboratory moved on a broader scale into environmental research. In March 1970, shortly before the first Earth Day celebrations, Weinberg expanded Auerbach's Ecology Section into an Ecological Sciences Division with studies of terrestrial, aquatic, and forest ecology underway and with an environmental studies program funded by the National Science Foundation and headed by John Gibbons which applied social and economic expertise to energy-related environmental challenges.

With the addition of radiological assessment and geosciences groups, the Ecology Division became the Environmental Sciences Division in 1972. The national requirement that environmental impact statements be prepared for new federal projects brought the new division considerable work, and the division formed an Environmental Sciences Information Center to support the preparation of impact statements and participated in a multidisciplinary study, led by William Fulkerson, Wilbur "Dub" Shults, and Robert Van Hook, of the ecological problems associated with fossil-fuel power plants.

In buildings constructed at the west end of the Laboratory grounds, the expansion of Environmental Sciences at the Laboratory continued into the 1990s. If not in name, the

Laboratory became in fact a national environmental assessment laboratory.

CONSTRAINTS

As early as 1967, Weinberg recognized that the costly Vietnam War was constraining the national budget for science. "Because of Vietnam, we shall be lucky to get as much money as we had this year," he told the staff. "We can only hope that Vietnam will be resolved quickly; and that, as peace is restored, we can devote ourselves and our expanding technologies to the creation of the better world."

The war did not end quickly and, in 1968, budgetary constraints forced retrenchments. Weinberg adamantly denied that the Laboratory's nonnuclear efforts were intended to counter the reductions in nuclear science budgets; in fact, he reminded critics that those efforts had begun long before the budgetary shortfalls of the late 1960s. Although Laboratory funding remained constant from 1965 to 1970, inflation eroded the funding's value by as much as twenty-five percent.

Other factors, in addition to the costs of the war, had a role in the declining budget. Because the AEC had determined to proceed with the liquid metal fast breeder reactor, it slashed funding from the Laboratory's molten salt thermal breeder program. As part of the social upheaval of the 1960s, strong antiscientific sentiment, marked by rowdy confrontations even at professional scientific conventions, also affected congressional support for research to some extent.

Weinberg and Laboratory staff witnessed several demonstrations against science by disillusioned youth. After seeing one in Boston in 1969, Weinberg wrote:

> We in Oak Ridge, living as we do in a sheltered and pleasant scientific lotus-land, just don't know what our colleagues in the beleaguered universities are up against. What a shock it is to go to the hub of the intellectual universe for what one expects to be a rather routine scientific meeting, and to run smack into a full-scale confrontation between the scientific establishment and the Angry Young People. I haven't had such an exciting time in years, certainly never at a scientific meeting.

At Christmas 1969, the Bureau of the Budget ordered across-the-board cuts at the Laboratory, reducing staff from 5300 to less than 5000. Its thermal breeder program was cut by two-thirds, and its proposed new particle accelerator, known as APACHE, was scrapped entirely. Departing friends made the 1969 holiday season in Oak Ridge as gloomy as that of 1947. In the close-knit Oak Ridge community, when friends lost their jobs, they usually had to leave to find work elsewhere.

"Our vast scientific apparatus is deployed against scientific problems--yet what bedevils us are strongly social problems," Weinberg lamented. "Can we somehow deploy our scientific instrumentalities, or invent new instrumentalities, that can make contributions to resolving these social questions?"

"We lost our innocence" about 1969, William Fulkerson, the Laboratory's Associate Director for Advanced Energy Systems, recalled years later. Realizing that scientific problems had social contexts as well as technical components, the chastened Laboratory entered the 1970s less innocent but perhaps more ready to meet the challenges of this tumultuous decade--one in which the nation would experience two energy crises and federally sponsored environmental programs that would forever alter the way the Laboratory conducted its business.

CHAPTER VI

THE RESPONSIVE LABORATORY

After thirty years of steady progress, fueled by internal discussion and debate, the Atomic Energy Commission (AEC) experienced a series of public events during the 1970s that dislodged confidence in nuclear energy. The events that affected the nuclear energy industry in general were reflected in dramatic changes in leadership within the AEC.

Chaired from the early 1960s until the early 1970s by chairman Glenn Seaborg, a Nobel laureate chemist associated with the Metallurgical Laboratory during World War II, the AEC was led subsequently by an economist, and then a marine biologist, before being split into the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC) in 1974. This division confirmed that the institutional framework, which had served nuclear power well in the years following World War II, would be insufficient to meet the energy challenges of the future.

If events within the AEC mirrored larger trends within the nuclear energy industry, then it also can be said that the Laboratory reacted to the dramatic transitions within the AEC with its own series of critical changes. Although not sundered like the AEC, the Laboratory transcended its traditional focus on uranium fission to undertake broader missions that encompassed all forms of energy. At the same time, Laboratory leadership passed from the hands of a fission expert to a nuclear fuel reprocessing specialist and, finally, to an expert in fusion energy.

With more powerful research reactors and accelerators added to its fleet during the 1960s, the Laboratory became a premier international center for producing and separating transuranic elements and researching their properties and for studying the structure and properties of nuclei with accelerated particles ranging from protons through curium and beyond. In support of the AEC reactor program, the Laboratory had pursued development of a molten salt reactor while it also investigated liquid metal and gas-cooled reactor technologies. By 1970, in response to the new political realities that the nuclear industry faced, the Laboratory also became a center for exploring the safety, environmental, and waste disposal challenges presented by nuclear energy.

The Laboratory's advance into new research frontiers was both a response to necessity and a deliberate effort to assume new challenges. Budget shortfalls between 1969 and 1973 shelved Laboratory plans for new reactors and reduced its staff from nearly 5500 in 1968 to fewer than 3800 by 1973. Moreover, the Laboratory's wartime veterans, now in their fifties and sixties, began to retire as the Laboratory's thirtieth anniversary neared in 1973. The departure of Oak Ridge's Manhattan project engineers and scientists left a void in the Laboratory's institutional culture that was progressively filled by a new generation who brought their own interests and experiences to the research agenda. Having come of age in the 1960s, this new generation brought somewhat different priorities and sensibilities to the workplace than had the Laboratory's original scientists, for whom World War II served as the defining moment in their careers.

To meet these challenges, Laboratory management reorganized and launched a series of retraining programs designed to transcend the Laboratory's traditional uranium fission focus. These new efforts led to investigations into all forms of energy --a broadening of research that made the Laboratory responsive to the political and social changes sweeping the nation.

In the aftermath of Earth Day in April 1970 and the passage of a series of environmental laws and regulations intended to bring environmental concerns to the forefront of the policy agenda, the public clamored for more "socially relevant" science that would address everyday concerns. In 1973, as Americans lined up to purchase gasoline and turned down their thermostats to compensate for heating-oil shortages, the desire for relevant science was never more urgent.

Laboratory efforts to explore new, nonnuclear energy issues during the early 1970s proved to be both timely and critical. Born at the dawn of the nuclear age and nurtured to maturity during nuclear power's great leap forward in the 1950s, the Laboratory was not about to abandon its ties to nuclear research. Nevertheless, as it experienced and then responded to the dramatic changes of the 1970s, the Laboratory emerged from this tumultuous decade a multipurpose science research facility, ready to tackle the increasingly complex issues of energy and the environment.

SUPER-DUPER COOKER

Although the high-flux reactor designed under Eugene Wigner's supervision in 1947 and built in Idaho provided the highest neutron flux then available, by the late 1950s the Soviets and Europeans had designed reactors that surpassed it.

"We do not believe the United States can long endure the situation of not having the very best irradiation facilities in the world at its disposal," commented Clark Center, Union Carbide chief at Oak Ridge. "Therefore, we would like to suggest that the Atomic Energy Commission undertake actively a design and development program aimed at the early construction of a very high-flux research reactor." Glenn Seaborg, an expert in transuranic chemistry, concurred with Center and urged the AEC to build a higher flux reactor.

With these statements of support echoing in Washington, Weinberg brought Wigner back to the Laboratory to discuss the design of a more powerful reactor, which Weinberg labeled a "super-duper cooker." Trapping a reactor neutron flux inside a cylinder encasing water-cooled targets, this high-flux isotope reactor would make possible "purely scientific studies of the transuranic elements" and augment the "production of...radioisotopes." Weinberg also insisted that the reactor be built with beam ports to provide access for experiments.

Charles Winters, Alfred Boch, Tom Cole, Richard Cheverton, and George Adamson led the design, engineering, and metallurgical teams for this 100-megawatt reactor, completed in 1965 as the centerpiece of the Laboratory's new transuranium facilities. Seaborg, appointed by President Kennedy to be AEC chairman, returned to the Laboratory in November 1966 for the dedication. He declared that the exotic experiments made possible by this new high-flux isotope reactor would "deepen our comprehension of nature by increasing our understanding of atomic and nuclear structure."

Built in Melton Valley across a ridge from the original X-10 site in Bethel Valley, the high-flux isotope reactor irradiated targets to produce elements beyond uranium at the upper and open end of the periodic table. At a heavily shielded transuranium processing plant adjacent to the reactor, A.L. "Pete" Lotts of the Metals and Ceramics Division led the teams fabricating targets that would subsequently be inserted into the reactor. In the reactor, the targets were placed in a very high neutron flux, where they absorbed several neutrons in succession, thus making their way up the periodic table as they increased in mass and charge. Then, they were returned to the processing plant for chemical extraction of the heavy elements berkelium, californium, einsteinium, and fermium in a program managed by William Burch.

MFIR

Previously available only in microscopic quantities, the grams of heavy elements produced at the high-flux isotopes reactor proved immensely valuable for research. The Laboratory distributed the heavy elements to scientists throughout the world and to its own scientists housed in the new transuranium research laboratory. "Our main effort at ORNL," said Lewin Keller, head of transuranium research, "is directed toward ferreting out their nuclear and chemical properties in order to lay a base for a general understanding of the field."

Of the transuranic elements, an isotope of element 98 garnered greatest attention. Named for the state where it was discovered, californium-252 fissions spontaneously and provides an intense neutron source, able to penetrate thick containers and induce fission in uranium-235 and plutonium-239. It could provide short-lived, on-site isotopes in hospitals for immediate use in patients. Cancerous tumors could be treated by implanting californium needles instead of less effective radium needles that had been used previously. Other transuranic elements also afforded practical applications--such as tracers for oil-well exploration and mineral prospecting.

Thanks to Weinberg's foresight in demanding beam ports, the high-flux isotope reactor could be used for many important investigations of materials by neutron scattering techniques. Studies were made of the magnetic properties, dynamical properties, and crystal structures of various materials by Wallace Koehler, Michael Wilkinson, Henry Levy, and their associates in the Solid State and Chemistry divisions. The intense neutron beams from the reactor coupled with state-of-the-

Laboratory's "bricks and mortar" reactor era. No new reactors would be built during the 1970s and 1980s, a remarkable dry spell given the rapidly changing nature of nuclear research.

Before being forced to close its doors on new reactor construction, in the 1960s, the Laboratory (in addition to its work on the high-flux isotope reactor) completed the health physics research reactor, the molten salt reactor, and performed research for the AEC's programs to develop a liquid-metal fast breeder reactor and for high-temperature gas-cooled reactors that stirred the interest of the private sector. Next to the high-flux isotope reactor, the most successful Laboratory reactor built during this decade may have been the health physics research reactor. HPRR

Known originally as the "fast burst reactor," the health physics research reactor was installed in the new dosimetry applications research facility in 1962. John Auxier, later director of the Health Physics Division, managed the design and operation of this small, unmoderated, and unshielded reactor.

Composed of a uranium-molybdenum alloy and placed in a cylinder eight inches high and eight inches in diameter, its operation required the insertion of a rod into the cylinder to release a neutron pulse used for health physics and biochemical research. In particular, data from research using the reactor, which remained operational until 1987, provided guidance for radiation instrument development and dosage assessment. During the 1960s, for example, it helped scientists estimate the solar art neutron scattering instrumentation allowed experiments to be performed that had not been possible previously. Of particular importance were numerous investigations involving the magnetic interactions of neutrons with materials, which helped explain some unusual magnetic properties of rare-earth metals, alloys, and compounds.

This reactor served science, industry, and medicine well for a quarter century. Although shut down because of vessel embrittlement in November 1986 and subsequently restarted to operate at eighty-five percent of its original power, by 1991 it had gone through 300 fuel cycles with immense benefits, ranging from advancing knowledge of materials by neutron scattering to enhancing understanding of U.S. history.

In 1991, for example, the high-flux isotope reactor's neutrons supported activation analysis of hair samples from the grave of President Zachary Taylor, which indicated he had not been poisoned by arsenic while in office, as some historians suspected. Americans could rest assured that President Taylor had died of natural causes--thanks to the use of 20th century technology in the service of 19th century history.

THE LAST REACTORS

Between the 1940s and 1960s, the construction of new reactors was part of the Laboratory's ever-changing landscape. The reactors built in the 1960s, however, would mark the end of evaluated the materials to be used in the fast breeder's heat exchangers and steam generator.

Work on the breeder accelerated in 1972, when the AEC made Oak Ridge the site of the AEC's demonstration fast breeder reactor. Laboratory efforts continued until Congress canceled the project in the mid-1980s, after more than a decade of political controversy and debate amid the gradual realization that the United States would not need a breeder reactor for twenty or more years.

THE "DARK HORSE" BREEDER

"A dark horse in the reactor sweepstakes." That's how Alvin Weinberg once described the Laboratory's molten salt reactor experiment to Glenn Seaborg. Weinberg explained that if Argonne's fast breeder encountered unexpected scientific difficulties, Oak Ridge's molten salt thermal breeder could serve as a backup that would help keep the AEC's research efforts on track.

Based on technology developed for the aircraft nuclear reactor, molten salt reactor experiments were conducted in the same building that had housed the aircraft reactor. Following the design and construction phases, molten salt reactor experiments began in June 1965. Project directors Herbert MacPherson, Beecher Briggs, and Murray Rosenthal successively supervised experiments using uranium-235 fuel.

When the fuel was changed to uranium-233 in October 1968, radiation doses affecting the Apollo astronauts.

When the AEC suspended work on the experimental gas-cooled reactor in 1964, light-water reactors became the dominant sources of commercial nuclear power. As a result, the Laboratory's gas-cooled reactor research waned. When Gulf General Atomic Corporation obtained orders for four high-temperature gas-cooled reactors in 1972, however, the AEC boosted Laboratory research funds for gas-cooled reactors. Under the general supervision of Donald Trauger, the Laboratory tested graphite-coated particles to fuel gas-cooled reactors. In addition, Laboratory studies of thorium fuel recycling accelerated because gas-cooled reactors could use uranium-233 derived from thorium as fuel.

This research continued until the commercial gas-cooled reactor built at Fort St. Vrain experienced operational difficulties, causing orders for similar reactors to be canceled. Laboratory studies of gas-cooled technology continued on a modest scale, often in collaboration with West Germany, where development of gas-cooled technology remained an important research goal.

Laboratory research into the liquid metal fast breeder reactor, which had been developed at Argonne National Laboratory, expanded during the late 1960s. William Harms directed the Laboratory's breeder technology program. His staff simulated the fast breeder's fuel assemblies, using electric heaters, and tested reactor coolant flows and temperatures under varying conditions, while a metallurgical team headed by Peter Patriarca

AEC chairman Seaborg joined Raymond Stoughton, the Laboratory chemist who co-discovered uranium-233, to raise the reactor to full power. "From here," said Rosenthal, "we hope to go on to the construction of a breeder reactor experiment that we believe can be a stepping stone to an almost inexhaustible source of low cost energy."

Weinberg and the Laboratory's staff pressed the AEC for approval of a molten salt breeder pilot plant. They hoped to set up the pilot plant in the same building that had housed the AEC's experimental gas-cooled reactor until that project was suspended in 1964.

Argonne's fast breeder had the momentum, however, and Congress proved unreceptive to Laboratory requests to fund large-scale development of a molten salt breeder. Appealing personally to Seaborg, a chemist, Weinberg complained: "Our problem is not that our idea is a poor one--rather it is different from the main line, and has too chemical a flavor to be fully appreciated by non-chemists."

Meanwhile, the experimental molten salt reactor operated successfully on uranium-233 fuel from October 1968 until December 1969, when the Laboratory exhausted project funds and placed the reactor on standby. The Laboratory continued molten salt reactor research, as limited funding allowed, until January 1973 when the AEC reactor division abruptly ordered work to end within three weeks.

In the wake of the energy crisis in late 1973, however, new funding for molten salt research emerged and continued until 1976. An exclusive Laboratory project, the molten salt reactor, in Weinberg's opinion, was the Laboratory's greatest technical achievement. His reasoning was based on the following observations: the molten salt reactor was feasible, could use uranium-233 made from abundant thorium as fuel, and offered greater safety than most other reactor types. As late as 1977, an electric utility executive advised President Carter of his company's interest in a commercial demonstration of the molten salt breeder reactor. The government's preoccupation with the liquid-metal fast-breeder reactor, however, drove Oak Ridge's thermal breeder into obscurity. To Weinberg's chagrin, the "dark horse" reactor never emerged from the shadows to lead the nuclear research effort.

ACCELERATORS

An evolution similar to the molten salt breeder program marked the Laboratory's accelerator program of the 1960s. The Laboratory's advanced particle accelerators, known as ORIC and ORELA, moved the Laboratory accelerator program, to the forefront of the nation's research efforts in this field. However, competition from other accelerator projects as well as funding constraints would stall the program in the early 1970s.

Although the Laboratory could produce transuranium elements up to number 100 in its high-flux isotope reactor, it could not produce the super-heavy elements, those with atomic numbers higher than 100, without building an advanced neutron source having an even higher flux.

The Oak Ridge isochronous cyclotron (ORIC) began operating in 1963, producing 60 MeV protons, 120 MeV alpha particles, and other light projectiles. To compensate for increases in the mass of ions as they are accelerated, the cyclotron had an azimuthally varying, but radially increasing, magnetic field to focus the particle's paths and keep them in resonance at high energies. In its day, ORIC was first of a kind and a major technological breakthrough.

Built on the east side of the X-10 site in Bethel Valley, the new cyclotron brought Robert Livingston's Electronuclear Division from the Y-12 to the X-10 site. In 1972, the Electronuclear Division consolidated with the Physics Division under the direction first of Joseph Fowler, followed by Paul Stelson, reporting to Alex Zucker, the associate director for physical sciences.

A year after ORIC obtained its first heavy ion beam, the Laboratory completed its Oak Ridge electron linear accelerator (ORELA) at a cost below the original estimate. Except for an office and laboratory building, this accelerator was underground, covered by twenty feet of earth shielding. Electron bursts traveled seventy-five feet along the accelerator tube to bombard a water-cooled tantalum target, producing ten times as many neutrons for short pulse operation than any other linear accelerator in the world. From the target room, the neutrons passed through eleven radial flight tubes to underground stations for experiments.

A joint project of the Physics and Neutron Physics divisions, ORELA's main purpose was to obtain fast neutron cross sections for the fast breeder reactor program. It served this purpose admirably, contributing a great deal to fundamental physical science. In 1990, for example, ORELA's intense neutron beams bombarded a lead-208 target and separated the three quarks composing a nucleon. This research effort advanced scientific understanding of the strong force that glues a neutron together.

By the time ORIC and ORELA were fully operational in 1969, the Laboratory had planned to build another machine capable of accelerating heavy ions into an energy range where super heavy transuranic elements could be investigated. With the support of universities throughout the region, this accelerator began as a southern regional project. In fact, the Laboratory considered naming it CHEROKEE (after one of the Southeast's most noted Native American tribes), but top scientists could not find the words to form an appropriate acronym; so it was named APACHE, the Accelerator for Physics And Chemistry of Heavy Elements.

Blanching at its $25-million cost, President Richard Nixon's budget office rejected the Laboratory's regional APACHE concept in 1969. Discussing the administration's unfavorable decision at AEC headquarters, Alex Zucker learned the budget office and the AEC would consider only national, not regionally sponsored, accelerators. To secure approval for an advanced accelerator, it would be necessary for the Laboratory to explain the unmet challenges of heavy ion research, show that it served "truly important national needs," and demonstrate that it would protect the United States from being surpassed in scientific research by other nations, particularly the Soviet Union.

Asserting that the proposed accelerator would advance understanding of "the behavior of nuclei in close collision and the properties of highly excited, very heavy nuclear aggregates," Zucker recommended that the Laboratory recast its new accelerator project in broader terms, naming it the National Heavy Ion Laboratory. Accepting this counsel, Weinberg established a steering committee headed by Paul Stelson to reformulate the proposal. The committee's efforts were fostered by a group of university physicists who saw value in having the accelerator located in Oak Ridge.

Led by physicists Joseph Hamilton of Vanderbilt University and William Bugg of the University of Tennessee, a consortium formed in 1968 to unite physicists from eighteen universities interested in heavy ion research at ORIC and the Laboratory's proposed national accelerator. Working with Robert Livingston and Zucker, the consortium obtained combined funding from their universities, state government, and the AEC to finance the construction of an addition to the ORIC building. The addition would house the university isotope separator (UNISOR), which would interface with an ORIC beam.

Only the Soviet Union had another on-line separator connected to a heavy ion accelerator. Equally important, this effort represented the first combined funding project for nuclear research hardware in the United States. When the separator facility was completed in 1972, UNISOR's consortium scientists initiated research into deformed nuclei, new radioisotopes for medical and industrial applications, heavy nuclei generation in the stars, and related challenges in the field of physics.

UNISOR's ongoing research and widespread academic participation provided the Laboratory with irrefutable proof that its proposed National Heavy Ion Laboratory would serve national needs. Budgetary constraints, however, caused this new facility not to be approved until 1974. Named the Holifield Heavy Ion Research Facility after Congressman Chet Holifield, the long-time chairman of the Joint Committee on Atomic Energy, this new accelerator was completed in 1980.

GOLD PLATED FUSION

Although the Laboratory's molten salt breeder and APACHE accelerator hit fiscal walls in 1969, the Laboratory's fusion energy research continued to receive funding under the stimulus of international competition. In 1969, the AEC authorized the Laboratory to construct a gold-plated fusion machine called ORMAK.

After a wildly optimistic, but essentially unsuccessful, entry into fusion energy research in the 1950s, the world's scientists recognized that a far better understanding of hydrogen plasma behavior was necessary before any real progress could be made. As a result, fusion scientists settled into the computer trenches during the 1960s hoping to improve the theoretical underpinnings of fusion energy. When it came to fusion, scientists faced two fundamental shortcomings: they were unsure whether it would work (in theoretical terms) and they were even more unsure of how to make it work (in practical terms).

At the Laboratory, attention focused on microinstabilities associated with the electric fields within the plasma of fusion devices. Empirical experiments continued with both a second direct current experiment and a steady-state fusion device conceived by Raymond Dandl and given the odd name ELMO bumpy torus. The electron cyclotron heating ELMO set a record for steady, stable hot-electron plasma.

Optimism about fusion resurfaced in 1968, when Soviet scientist L.A. Artsimovich of Moscow's Kurchatov Institute announced his doughnut-shaped tokamak had confined a hot plasma. When Artsimovich visited the United States in 1969, Herman Postma, the Laboratory chief of fusion research, dispatched a Laboratory team to discuss tokamaks with him.

Enthusiastic about what they heard, Postma's team proposed to the AEC the construction of a tokamak at the Laboratory. They received quick approval, together with a mandate to have it operational by 1971. While the Oak Ridge tokamak, called ORMAK, brought the Laboratory back into a race with the Soviets, Artsimovich and other Soviets, in the unique cooperative spirit that characterized fusion research even during the Cold War, provided helpful information for ORMAK's design.

Sometimes working three shifts daily, the Laboratory's thermonuclear staff, with assistance from skilled craftsmen at Y-12, rushed ORMAK's construction. The plasma was inside a doughnut-shaped vacuum chamber (torus) of aluminum with a gold-plated liner. Coils of electrical conductors cooled by liquid nitrogen provided the magnetic field. Michael Roberts, ORMAK's project leader, described the assembly of this complicated machine as an unusual exercise like "putting an orange inside an orange inside an orange, all from the outside."

In the summer of 1971, ORMAK generated its first plasma and experiments began, with encouraging results achieved by 1973. Herman Postma worried, however, whether the high speed neutrons they generated would destroy the fusion reactors. Materials had to be found for fusion reactor walls that would withstand the particle damage and stresses before the ORMAK or other fusion devices could generate even a shimmer of interest among commercial power producers.

More optimistic, Weinberg noted that the ORMAK design permitted the installation of a larger vacuum chamber ring (torus) that would become ORMAK II. "With great good luck," he forecast, "ORMAK II might tell us that it would be a good gamble to go to a big ORMAK III, which might be the fusion equivalent of the 1942 experiment at Stagg Field in Chicago." Elusive plasma slipped from ORMAK's golden grip, however, and neither ORMAK nor subsequent fusion machines have yet achieved a self-sustaining fusion reaction.

NUCLEAR ENERGY AND THE ENVIRONMENT

While basic science and experimental reactor and accelerator hardware dominated activities within the Laboratory, political, legal, and popular protests far from the Oak Ridge reservation contributed mightily toward reorienting its missions after 1969.

Although dozens of reactors for commercial power production were then in the planning and construction phases, the nuclear industry remained troubled by three concerns: fission reactor safety, power plant environmental impacts, and safe disposal of fission wastes. These concerns also challenged the Laboratory, and it led in considering the broader aspects of radioactive waste disposal.

After thirteen years of study, the Laboratory proposed entombing high-level radioactive wastes in deep salt mines near Lyons, Kansas, and in 1970 the AEC provided $25 million to proceed with the salt mine repository.

Noting that the wastes would be hazardous for thousands of years, Weinberg warned, "We must be as certain as one can possibly be of anything that the wastes, once sequestered in the salt, can under no conceivable circumstances come in contact with the biosphere." Laboratory scientists concluded that the salt mines, located in a geologically stable region, would not be affected by earthquakes, migrating ground water, or continental ice sheets that might reappear during the waste's long-lived radioactivity.

People living near Lyons supported the Laboratory's salt vault plan, but environmental activists and Kansas state officials opposed use of the salt mines on several grounds. Their concerns extended beyond questions of technical capability to deep-seated worries about sound and effective administration over the long haul. Activists claimed that underground disposal for millennia would require the creation of a secular "priesthood" charged with warning people never to drill or disturb the burial grounds. "It is our belief that disposal in salt is essentially foolproof," replied Weinberg, although conceding that a "kind of minimal priesthood will be necessary."

During intense design studies in 1971, the Laboratory and its consultants found that the many well holes already drilled into the Lyons salt formation might in some circumstances allow groundwater to enter the salt mines, thus raising technical questions about the site's long-term suitability. The salt mine disposal plan also became a heated political issue in Kansas. In 1972, the AEC authorized the Kansas geological commission to search for alternative salt mines in Kansas and directed the Laboratory to study salt formations in other states. For the moment, the AEC announced, radioactive wastes would be solidified and stored in aboveground concrete vaults at the site of their origin. That moment has turned into decades, as scientific and political debates concerning radioactive waste disposal issues continue to this day, and are not likely to be resolved soon.

Public and legal concerns about the environmental effects of nuclear power brought the Laboratory's studies of terrestrial and aquatic habitats to the forefront of its research agenda during the early 1970s. Using the "systems ecology" paradigm pioneered by Jerry Olson, Laboratory ecologists investigated radionuclide transport through the environment. Olson examined the migration of cesium-137 through forest ecosystems, inoculating tulip poplar trees behind the health physics research reactor with cesium-137, and thereby establishing the first experimental research center for forest ecosystem studies. In 1970, the National Science Foundation placed Stanley Auerbach in charge of a deciduous forest biome program in which the Laboratory contracted with universities for studies of photosynthesis, transpiration, insects, soil decomposition, nutrient cycling, and related fundamental investigations of forest systems in the eastern United States.

David Reichle led the Laboratory's forest research team which initiated large-scale forest ecosystem research in 1970 in Oak Ridge. This was the forerunner of the Laboratory's programs twenty years later for investigation of acidic deposition, biomass energy production, and global climatic change.

Environmental studies at the Laboratory received an unexpected boost in 1971 when a federal court, in a decision on a planned nuclear plant at Calvert Cliffs, Maryland, ordered major revisions of AEC environmental impact statements as an essential part of reactor licensing procedures. Required to complete 92 environmental impact statements by 1972, the AEC asked for help from its Battelle Northwest, Argonne, and Oak Ridge national laboratories. Giving this effort the highest priority, Weinberg declared, "Nuclear energy, in fact any energy, in the United States simply must come to some terms with the environment."

The Laboratory's skeleton staff for environmental impact statements, headed by Edward Struxness and Thomas Row, expanded in 1972 to include 180 scientists and technicians, divided into discipline-oriented teams to rapidly prepare these applied ecology and socioeconomic reports. The staff who worked on these reports formed the nucleus of the Energy Division, established in 1974 under Samuel Beall's leadership.

The Calvert Cliffs decision required the AEC to consider the effects of the heated discharge of cooling water from nuclear plants on the aquatic environment, and Charles Coutant led a Laboratory team assigned the task of developing federal water temperature criteria to protect aquatic life. For these and related studies, the Laboratory initiated construction of an Aquatic Ecology Laboratory, completed in 1973. Only the Pacific Northwest Laboratory had a similar laboratory. Its initial equipment consisted of twenty water tanks, each containing various fish species under study, and a computer-controlled circulating heated water system to supply proper temperature water to the tanks; outside were six ponds for breeding fish and conducting field experiments. Early experiments at the aquatics laboratory investigated the survival rate of fish and fish eggs at elevated temperatures.

One immediate result of the aquatic studies came during environmental studies for the Indian Point-2 nuclear plant on the Hudson River, just north of New York City. Because the Environmental Sciences Division identified Indian Point as a major spawning ground for striped bass, the impact statement for Indian Point-2 included a recommendation for closed cycle cooling towers, to prevent the warming of the spawning ground and to protect all aquatic life from the adverse effects of thermal discharges. This decision was based on ecosystem modeling of the striped bass by Siegurd Christensen and Webb Van Winkle and is considered one of the high points of environmental impact statement preparation at the Laboratory.

The high cost of environmental mitigation, reflected in the costs of constructing cooling towers and elaborate water cooling systems, concerned many nuclear power advocates, who were troubled as well by the stringent reactor safety standards that the Laboratory staff proposed in 1970. Under the direction of Myer Bender of General Engineering Division, the Laboratory had issued nearly one hundred interim safety standards. Many of these standards were based on investigations by the Heavy Section Steel program conducted in the Reactor and Metals and Ceramics divisions. Other standards relating to reactor controls were developed by the Instrumentation and Controls Division.

William Unger and his associates, for example, designed and tested shipping containers for radioactive materials to determine the design that could best withstand collisions during transport. Richard Lyon and Graydon Whitman assessed the ability of reactors to withstand earthquakes, joining with soil engineers who simulated mini-earthquakes by detonating dynamite near the abandoned gas-cooled reactor. George Parker's team studied fission product releases from molten fuels, and Philip Rittenhouse's team investigated the failure of engineered safeguards, particularly the effects of interruptions in the water flow to reactors.

EMERGENCY CORE COOLING HEARINGS

"We find ourselves increasingly at those critical intersections of technology and society which underlie some of our country's primary social concerns," Weinberg declared in 1972. He also noted that Laboratory veterans longed for the days when "what we did at ORNL was separate plutonium, measure cross sections, and develop instruments for detecting radiation."

Those days were part of the Laboratory's history and were lost in the heated climate of political discourse and public opinion that emerged during the Emergecy Core Cooling Systems (ECCS) hearings in 1972.

The AEC Hearings on Acceptance Criteria for Emergency Core Cooling Systems for Light-Water-Cooled Nuclear Power Reactors, called the ECCS hearings for short, proved a critical event, one that forced the Laboratory to face the harsh realities of the new nuclear era of controversy, conflict, and compromise.

In 1971, President Nixon appointed James Schlesinger, an economist from his budget office, to succeed Glenn Seaborg as AEC chairman. Schlesinger aimed to convert the AEC from an agency that unabashedly promoted nuclear power to one that served as an unbiased "referee." When protest greeted the AEC's interim criteria for emergency core cooling systems, he convened a quasi-legal hearing for comments from reactor manufacturers, electric utility officials, nuclear scientists, environmentalists, and the public. The hearing began in Bethesda, Maryland, in January 1972 and lasted throughout the year.

To present their views, environmental groups hired attorneys and scientific consultants, who joined attorneys for reactor manufacturers, utilities, and the government to pack the ECCS hearings. Witnesses were subjected to dramatic cross-examinations--a new experience for most scientists, who were accustomed to establishing scientific truth through the sedate publications and peer review process, not through adversarial legal proceedings.

As long as nuclear reactor power was less than 400 thermal megawatts, their containment vessels could prevent a meltdown, or the type of accident popularly called the "China syndrome." Once reactors of greater power were designed, however, the containment vessel no longer could be counted on as the final defense; an emergency core cooling system became imperative to protect the public. Weinberg thought it unfortunate that some AEC staff members had not been impressed by the seriousness of this requirement until forced to confront it by activists opposed to nuclear energy altogether.

Schlesinger agreed with Weinberg that Laboratory staff should present their expertise fully and without reservation, regardless of whether they agreed with the interim criteria. Weinberg complained, however, that his staff should have been involved as fully in preparing the interim criteria as they would be in testifying at the hearings.

Among Laboratory staff participating in these lengthy, sometimes contentious, sometimes tedious, hearings were William Cottrell, Philip Rittenhouse, David Hobson, and George Lawson. They and other witnesses were grilled by attorneys for days. More than 20,000 pages of testimony were taken from scientists and engineers, who often expressed sharp dissent on technical matters concerning the adequacy of the safety program. The Laboratory's experts generally considered that the interim criteria for reactor safety were based on inadequate research.

As a result of these showdown hearings, in 1973 the AEC tightened its reactor safety criteria to reduce the chances that reactor cores would overheat as a result of loss of the cooling water. This measure, however, failed to placate critics who preferred a moratorium on nuclear reactor construction.

The Laboratory emphases on reactor safety and environmental protection made the Laboratory and Director Weinberg unpopular among some nuclear power advocates and members of the AEC staff--a strange turn of events for scientists who had devoted their careers to inventing and advancing practical applications of nuclear energy. Opponents of nuclear power, on the other hand, enjoyed quoting Weinberg's chilling declaration:

> Nuclear people have made a Faustian Contract with society; we offer an almost unique possibility for a technologically abundant world for the oncoming billions, through our miraculous, inexhaustible energy source; but this energy source at the same time is tainted with potential side effects that if uncontrolled, could spell disaster.

Although other events and considerations also played a part, the ECCS hearings of 1972 no doubt weighed heavily on the major management shifts that occurred at the Laboratory and at the AEC in 1973. Certainly, they influenced the decision by the president and Congress to divide AEC functions, separating its regulatory responsibilities from its other activities. As a result, the greatest transition in energy research and development since 1946 began and continued throughout the mid-1970s.

ENERGY TRANSITION

Another crisis--not in public confidence but in energy supplies--threatened the nation during the early 1970s. To meet this challenge, Weinberg sought to reorient and broaden the

Laboratory's mission. He was encouraged both by the National Science Foundation and the AEC, which in 1971 received congressional approval to investigate energy sources other than nuclear fission. At AEC headquarters, James Bresee, who had headed the Laboratory's civil defense studies, became head of a general energy department, which managed funding for Oak Ridge's innovative energy studies.

When Congress authorized the AEC in 1971 to investigate all energy sources, Weinberg appointed Sheldon Datz and Michael Wilkinson to head a committee and subcommittee to review opportunities for nonnuclear energy research in the basic physical sciences. In addition, he made Robert Livingston the head of an energy council assigned the task of considering new Laboratory missions.

At the AEC, James Bresee approved Laboratory proposals for research into improved turbine efficiency, alternative heat disposal methods at powerplants, coal gasification, high-temperature batteries, and methods for producing synthetic fuels, such as hydrogen, to replace petroleum and natural gas.

The AEC-sponsored studies complemented related studies begun in 1971 under the auspices of the National Science Foundation (NSF). Charged with sponsoring "socially relevant" science, the NSF in 1970 sponsored interdisciplinary research at the Laboratory slanted toward addressing broad societal problems. Led by David Rose and John Gibbons, this research focused on energy, renewable resources, recycling, and regional modeling. In broad terms, it sought to identify nationally significant problems that the Laboratory could address.

When the NSF announced its "research applied to national needs," or RANN, program in 1971, Weinberg advised NSF director William McElroy that the Laboratory had "rather miraculously" identified many national needs for research that it could conduct. A poll of Laboratory staff produced 150 new energy and environmental research proposals; the NSF approved a few of them. These efforts were guided by Wilbur "Dub" Shults, Robert Van Hook, and William Fulkerson.

Noting that many environmental problems arose as a result of increasing energy use, Roger Carlsmith, Eric Hirst, and their associates initiated studies that examined ways to reduce energy demand by promoting energy conservation. In 1972, they asserted that better home insulation could substantially cut energy use for home heating. Moreover, they concluded that increasing the efficiency of transportation modes and home appliances could significantly lower the levels of energy consumption. These early efforts launched the Laboratory's energy conservation research efforts, which became one of the Laboratory's great strengths.

To promote the design of more efficient central power stations, the Laboratory studied improved turbine cycles, cryogenic power transmission lines, and "power parks" to cluster power stations outside urban areas. Arthur Fraas and his associates, for example, applied the potassium vapor technology they had developed for spacecraft to improve the turbine efficiency at power stations.

Interest in solar energy flared in 1971, when solar energy advocate Aden Meinel visited the Laboratory and proposed using solar energy to heat liquid-sodium and molten salts for large-scale generation of electricity. Murray Rosenthal, who headed the Laboratory's molten salt reactor experiment, led a group that assessed the economics of using heat from the sun to produce electricity.

Although the group concluded that solar power generation would cost more than nuclear or fossil fuel power, Rosenthal recommended additional studies because solar energy could ultimately prove economically attractive if two possible scenarios became a reality: "One is that environmental concerns or other factors could increase coal and nuclear energy costs more than we can foresee; the other is that the collection and conversion of solar energy could become much less costly than we assume."

With NSF backing, the Laboratory examined solar energy as a potential long-term backup for other energy sources. In addition, David Novelli and Kurt Kraus studied the use of solar heat to enhance biological production of hydrogen and methane fuels as petroleum substitutes. The Laboratory's knowledge of surface physics and semiconductors eventually led to investigations of photovoltaic cells by Richard Wood and associates in the Solid State Division as part of the Laboratory's modest solar program.

MANAGEMENT TRANSITION

The Laboratory's 1971 venture into nonnuclear energy research did little to ease its fiscal woes. Successive annual budget reductions in its nuclear energy programs forced corresponding reductions in staff and continuous efforts to lower overhead. As one cost-cutting measure, the Laboratory closed its food service canteens scattered about the complex for employee convenience and replaced them with vending machines.

Typical of his management style, Weinberg appointed long-range planners to identify supplemental Laboratory missions. Commenting that he felt at times "like a man with a canoe paddle trying to change the course of an ocean liner," David Rose, the first long-range planner, returned to MIT. Robert Livingston succeeded Rose as head of the program planning and analysis group, which included Calvin Burwell and Frank Plasil. Squarely facing the transition in Laboratory missions, this group proposed a staff education program to retrain fission specialists in broader energy and environmental issues.

Musing on this proposal, Weinberg recognized the dilemma of having experts trained in one select field while funding opportunities were becoming more prevalent in other fields. He noted that a similar redirection had marked the experience of Manhattan project personnel during and after World War II. Wigner, a chemical engineer, switched to nuclear physics. Cosmic-ray specialist Ernest Wollan became a health physicist and neutron diffraction expert. Biochemist Waldo Cohn became expert in the chemistry of radioisotopes and nucleic acids, and biochemist Kurt Kraus became highly skilled in plutonium chemistry. Weinberg himself had started his career as a biophysicist, only to become a reactor physicist.

"Enrico Fermi once told me that he made a practice throughout his scientific career of changing fields every five years," Weinberg recalled. He added that, although "there are few Fermis, I think we all easily recognize that the spirit of his advice can well be helpful."

In an effort to enhance internal viability and flexibility, in 1972 the Laboratory initiated a school of environmental effects aimed at producing physical scientists conversant with biology and ecology. This effort stalled, however, because most members of the school were laid off during the massive reduction in force of 1973. Taking cues from his own observations about the Laboratory's future, Weinberg, after a quarter century of service at Oak Ridge, also embarked on a new career.

The long-time Laboratory Director joined Herbert MacPherson and William Baker, president of Bell Laboratories, to form a "think tank" dedicated to coherent long-range energy planning. With support from the AEC and John Sawhill of the Federal Energy Office, they created the Institute for Energy Analysis in late 1973. The Oak Ridge Associated Universities served as the institute's contractor/operator. It opened in January 1974 with Herbert MacPherson as director because Weinberg had been called to Washington to lend his expertise to resolving the national energy crisis.

Throughout 1973, Floyd Culler served as acting director of the Laboratory. A chemical engineer with a degree from Johns Hopkins University, Culler had worked at the Y-12 plant during the war and joined the Laboratory in 1947, rising through the ranks to become a world renowned expert on chemical reprocessing of nuclear fuels. He directed the Chemical Technology Division and served as assistant director before succeeding MacPherson as deputy to Weinberg in 1970. Described as a "muddy boots type," Culler received acclaim at the fourth Geneva conference on atomic energy in 1971 for objecting to plans by other nations to store liquid nuclear wastes in tanks. He contended that bequeathing radioactive wastes to future generations without providing a permanent, safe disposal system posed serious political and moral questions.

Culler's year as Laboratory director resembled a roller coaster ride, which he later described as a "year of many transitions." In January 1973, Milton Shaw, chief of AEC reactor development programs, mandated a quick end to the Laboratory's molten salt reactor studies. This decision precipitated what Culler described as the "largest and most painful reduction of employment level at the Laboratory in its history." It also undermined the morale of the fewer than 3800 personnel who remained at the Laboratory.

The highlight of Culler's year was the Laboratory's participation in the national energy strategy. In March 1973, President Nixon appointed Dixie Lee Ray, a marine biologist, as AEC chairman to replace James Schlesinger, who became Secretary of Defense. When the President asked Ray to review energy research and recommend an integrated national policy, she called on the national laboratories to assist in undertaking these urgent studies. Oak Ridge provided background information for Ray's report, titled "The Nation's Energy Future," which advocated energy conservation to reduce demand as well as research into new technologies and strategies to increase supplies. The report's ultimate goal was to make the nation independent of imported fuels by 1980.

The turnaround for Laboratory programs came on the heels of the Yom Kippur War in the Middle East and the related Arab oil embargo of October 1973. As disgruntled Americans lined up at filling stations to purchase gasoline, Nixon established the Federal Energy Office. With William Simon as director and John Sawhill as deputy director, the office was responsible for allocating scarce oil and gas supplies during the emergency, and for planning long-range solutions to the nation's energy problems.

At Sawhill's request, Weinberg went to the White House to head the Office of Energy Research and Development. Because Nixon did not appoint a presidential science advisor as had Presidents Eisenhower, Kennedy, and Johnson, Weinberg became science's sole delegate to the White House during the late Nixon and early Ford administrations.

Floyd Culler noted that the oil embargo and energy crisis made the Laboratory "whole again" by the end of 1973. Reacting to this crisis, Congress pumped new funding into energy research and even approved a modest resumption of molten salt breeder studies at the Laboratory. "Throughout ORNL's evolution, its central theme has continued to be the development of safe, clean, abundant economic energy systems," Culler said at the end of the year. "The Laboratory is now in a uniquely strong position to undertake a multimodal attack on the nation's energy problems."

In December 1973, President Nixon proposed a reorganization of the federal energy agencies. As part of this effort, he divided the AEC into two new agencies. AEC responsibilities for energy research and development went to the Energy Research and Development Administration, while AEC regulatory responsibilities were assumed by the Nuclear Regulatory Commission.

With this new administrative structure in place, Eugene Wigner recommended a Laboratory reorganization paralleling the division of the AEC. He urged that Weinberg be returned to the Laboratory to manage its energy research and development programs and that Culler be assigned responsibility for the Laboratory's safety and environmental programs. "Alvin and Floyd Culler have collaborated for several years," Wigner asserted, and "they understand, like, and respect each other." As a result, he said, "conflicts are most unlikely to arise."

Wigner's recommendation was not accepted. Weinberg served the White House until formation of the Energy Research and Development Administration in late 1974 and then became director of the Institute for Energy Analysis in Oak Ridge. Culler stayed at the Laboratory as deputy director under Herman Postma until 1977, when he became president of the Electric Power Research Institute.

The Laboratory's and AEC's transitions were completed by 1974. Headed successively from 1971 to 1974 by a transuranic scientist, an economist, and a marine biologist, the changes at the AEC ended with its division into two new organizations in 1974.

Changes at the Laboratory were no less dramatic during these years. Managed successively by a fission scientist, a chemical processing specialist and, in 1974, by a fusion energy professional, it transcended its nuclear fission heritage to become a national laboratory embracing all forms of energy.

Life at the Laboratory may have become more tumultuous during the 1970s, but changes in the Laboratory's workplace were no more--or less--than a reflection of dramatic changes in American society. Isolated in the serene hills of East Tennessee, the Laboratory could not avoid being caught in the vortex of a changed energy world. Its future would depend on how well it could respond to the new world "energy" order that suddenly emerged in the aftermath of the Arab oil embargo of 1973 and the ensuing energy crisis.

CHAPTER VII

THE ENERGY LABORATORY

"After five years of steady decline, much personal distress, and a deep sense of frustration...that...obvious national problems were not being attacked," Laboratory Director Herman Postma said, "1974 is the year in which we perceive an end to such dismay." Warnings of energy shortages, Postma added, "finally hit home as the Arab oil embargo began and people had to wait in gas lines."

The 1974 energy crisis and Postma's selection as director during the same year had far-reaching implications for the Laboratory. Scion of a North Carolina Dutch farming family, Postma had spent summers at Oak Ridge while enrolled as a physics student at Duke and Harvard universities. He joined the Laboratory's Thermonuclear Division in 1959 and became division director in 1968 at the age of 40. Postma not only assumed his position at a remarkably young age, he was also the first Laboratory director without direct Manhattan District experience.

In a broader context, his ascent symbolized the arrival of a new generation of scientists--the "young turks." These youthful scientists displayed as much interest in bioreactors, coal reactors, and fusion reactors as the Laboratory's earlier researchers--now the "grey eagles"--had exhibited in nuclear reactors.

In response to demands from these younger scientists, Postma limited the terms of the Laboratory's division directors and established a system of rotating management. While Weinberg had served in a dual capacity as both Laboratory Director and as chief of the Director's Division, Postma divested himself of the dual role. The Director's Division was replaced by central management offices, under the direction of Frank Bruce, Associate Director for Administration. Postma also set aside time each week to listen to any Laboratory employee wishing his personal attention.

Turks and eagles may have disagreed about the Laboratory's research agenda, but both groups were pleased by a broad exploratory studies initiative begun in 1974. Dubbed the Seed Money Program, it aimed to encourage creative science. "Scientific advances are made by individuals in the privacy of their own minds," observed Alex Zucker, explaining the seed money rationale. "It is one of the functions of a scientific laboratory," he continued, "to discover the unexpected, to develop new ideas, and to explore in an unfettered way areas that may not show much promise to the casual observer."

Laboratory overhead funded seed money research proposals that review committees thought promising, especially initiatives that the committee members thought had latent potential for acquiring additional funding from other federal agencies. Loucas Christophorou's study of the breakdown of insulating gases, David Novelli's amino acid research, and Elizabeth Peelle's socioeconomic analysis of power plant impacts on neighboring communities were three successful seed money projects funded in 1974.

By 1977, funding had increased to $1 million, covering start up costs for 15 creative proposals. The program remained in place in 1992, and eagles and turks, as well as the hawks of the 1990s, viewed this initiative as one of management's most successful programs.

WHAT'S IN A NAME

To Postma's surprise, in late 1974 he found himself with a new job title. No longer head of Oak Ridge National Laboratory, he became the director of Holifield National Laboratory instead--same job, same place, different title.

Late that year, aides to the congressional committees on atomic energy and government operations memorialized their retiring chairman by renaming the Laboratory after Congressman Chet Holifield of California. Done without consulting Oak Ridge community leaders or Laboratory officials, the name change met local disapproval, although Holifield was a respected friend of Oak Ridge. "I recognize the role Holifield's played," admitted Howard Adler, director of the Biology Division, "but the name ORNL has worldwide significance and recognition that can't be tossed aside lightly."

Responding to this concern, Senator Howard Baker, Congresswoman Marilyn Lloyd, and members of the Tennessee congressional delegation sought to restore the name Oak Ridge. In the interim, Postma and Laboratory management used Holifield National Laboratory for official government business and the familiar Oak Ridge nomenclature in scientific circles.

This uncomfortable conundrum ended late in 1975, when Congress reinstated the title Oak Ridge National Laboratory and named the national heavy ion research center, a 150-foot tower under construction for the Laboratory's giant accelerator, the Holifield Heavy Ion Research Facility.

More challenging than the name game was the Laboratory's response to the energy crises of the 1970s. To address the fuel and heat shortages of the winter of 1974, Postma appointed Edward Witkowski and Charles Murphy the Laboratory's energy coordinators. Lights were dimmed and heating levels were lowered in buildings throughout the complex, and gasoline was rationed for the Laboratory's fleet of vehicles.

Taking these sacrifices in stride, Laboratory employees donned sweaters and joined carpools to get to work. Even the Laboratory's garage staff accepted the conservation challenge, undertaking applied fuel research by converting vehicles from gasoline to methanol fuel. The vehicles seemed to run well and burn fuel more cleanly.

In total, emergency conservation reduced Laboratory energy use by seven percent in 1974. Improved building insulation cut energy consumption even more throughout the decade.

Congress responded to the energy crisis by boosting the national budget for energy research, a move that helped warm and brighten (at least symbolically) the Laboratory's cold, dim corridors. Equally important, the energy crisis fueled congressional discontent with the Atomic Energy Commission (AEC), which had already been under fire over questions about how well it was fulfilling its safety oversight responsibilities in nuclear energy.

In 1974, Congress voted to divide the AEC into two separate agencies: the Energy Research and Development Administration (ERDA), which would serve as the federal government's energy research arm, and the Nuclear Regulatory Commission (NRC) which, as the name implies, would be responsible for regulating and ensuring the safety of the nation's nuclear energy industry.

Ending twenty-eight years of service, the AEC closed at the end of 1974. Among the AEC staff locking the commission's doors for the last time was Alvin Trivelpiece, later to succeed Postma as Laboratory Director.

ERDA absorbed the AEC laboratories, plus the Bureau of Mines coal research centers, and other federal laboratories with energy-related missions. In all, it inherited fifty-seven laboratories, research centers, and contractors--with approximately 91,000 employees--and it was eager to put them to work on the nation's urgent energy problems. The Laboratory became one of many ERDA laboratories, although its reactor safety and environmental programs also supported NRC licensing and regulatory activities.

Because no definition of laboratory roles and their relationships to other ERDA responsibilities was in place in 1974, questions about the laboratories' organization, planning, and accounting systems arose.

The ERDA Director, former Air Force Secretary Robert Seamans, formed a committee of advisors, including Herman Postma, to help plan the reorganization. Postma soon learned that ERDA would demand rapid applications of technology to improve the national energy posture. An ERDA official warned Postma and other laboratory directors: "If you are not working on energy projects having a good chance of being in the Sears-Roebuck catalog in five years, then you are working for the wrong agency."

ERDA's sense of urgency propelled the Laboratory into a broad range of energy-related research endeavors that some wag dubbed "coconuke"--conservation, coal, and nuclear energy. At Oak Ridge, ERDA added fossil fuel and energy conservation programs to the Laboratory's traditional nuclear fission and fusion energy missions--an effort that fit nicely into the broad research agenda of the young turks.

As part of its response to the expanded mandate, the Laboratory formed an Energy Division in 1974 reporting to Murray Rosenthal, associate director for Advanced Energy Systems. Samuel Beall served as Energy Division's first director; he was followed one year later by William Fulkerson.

This new division absorbed the environmental impact reports group, the National Science Foundation environmental program, an urban research group, and nonnuclear studies from the Reactor Division under one administrative umbrella. The Energy Division sought to tie energy research and conservation to broad questions of social and environmental impacts. In effect, the Laboratory was acknowledging within its administrative framework that energy research could no longer be confined to narrow technical issues.

ENERGY CONSERVATION

Recognizing that the nation's energy posture could be improved by curbing the consumption of existing energy resources and putting wasted energy to use, the Laboratory joined ERDA's national conservation program. Through many small enhancements in energy conservation, the Laboratory and ERDA expected in the aggregate to reduce national energy use by several percentage points annually.

Some conservation research emanated from the Laboratory's earlier studies of the potential environmental impacts of nuclear power plants. Having observed the wasting of heat from these plants into the water or air, the Laboratory proposed putting the wasted heat to use for warming greenhouses to grow plants and ponds to raise fish for food. As an outgrowth of Laboratory recommendations, TVA and electric power utilities undertook experiments with greenhouses and related heat-use facilities that could be factored into the design, construction, and operation of their nuclear plants during the 1970s.

The Laboratory proposed similar uses for waste heat, called cogeneration, for a modular integrated utility system it blueprinted for the Department of Housing and Urban Development (HUD). In this design for small communities, heat from an electric generating plant for a modular community also would supply space heating and hot water for the community.

With funding from HUD, ERDA, and the National Science Foundation, six Laboratory divisions, including the Energy Division, launched a comprehensive set of programs to foster energy conservation in 1974. Moreover, because of its strict personnel ceilings, ERDA asked the Laboratory to act as its program manager for conservation efforts throughout the energy agency's sprawling federal network.

For ERDA headquarters, the Laboratory planned conservation programs, awarded subcontracts for research and engineering, and monitored and reviewed the work. Many of these responsibilities were carried out by the Laboratory's residential conservation program headed by Merl Baker and Roger Carlsmith. The program supported studies of improved home insulation, tighter mobile home design, advanced heating and cooling systems, and energy-efficient home appliances.

When ERDA asked the Laboratory to assess how much energy could be saved by better insulating homes and businesses, Ralph Donnelly, Victor Tennery, and colleagues undertook a study which, in 1976, reported that improved insulation was crucial to national energy conservation. The Laboratory emerged as ERDA's prime agency for developing thermal insulation standards, later adopted by ERDA, the Department of Commerce, and building trade associations. These standards helped generate substantial and continuing savings for homeowners while paring national energy consumption. Retrofitting existing buildings to save energy followed when utility systems such as TVA financed improved home insulation, heat pumps, and other energy conservation measures in existing structures.

Manufactured homes promised energy savings that would probably exceed conservation efforts in more conventional structures. Laboratory studies, led by John Moyers and John Wilson, sought to determine the potential savings. "Mobile homes are produced in factories," Moyers pointed out, "and should be more susceptible to quality control, unified system design, and engineering...than custom-built homes."

Equipping a mobile home at the Laboratory with instruments to measure its power use and seasonal temperature fluctuations, researchers were able to establish tighter insulation and storm window standards subsequently adopted by the American National Standards Institute and the U.S. Department of Housing and Urban Development (HUD) to upgrade mobile home efficiency. Those who purchased new mobile homes, often recently married couples or retirees with limited incomes, enjoyed reduced energy costs, and the nation as a whole cut its energy consumption.

Harry Fischer's annual cycle concept may have been the most publicized Laboratory energy conservation endeavor. A retiree with wide experience in energy engineering, Fischer dropped by the Laboratory in 1974 to tell Samuel Beall, new chief of Energy Division, he knew how to provide home heating, air conditioning, and hot water at half the cost of systems then in use. His annual cycle system used a heat pump which, instead of taking heat from the outside air and pumping it into a house during winter, extracted heat from a large insulated tank of water, changing the water into ice for summer cooling.

Returning home to Maryland, Fischer discussed his concept with his neighbor, Secretary of Interior Rogers Morton, who offered support if Fischer and the Laboratory could produce a working model within three months. They had it operating in two. Fischer also met John Gibbons, head of the University of Tennessee Energy, Environment, and Resources Center, who was overseeing a university-sponsored project to construct a solar heated home and a conventionally heated home near Knoxville for comparative research. After talking with Fischer, Gibbons agreed to construct a third home adjacent to the other two that would use Fischer's annual cycling system. Jointly managed by the university, the Laboratory, TVA, and ERDA, the houses were completed in a year. ERDA Director Seamans personally inspected the annual cycling system house to highlight it as an example of the fast action he demanded. As Fischer predicted, the annual cycling system house could be heated and cooled at half the energy costs of a conventional heating and cooling system, Few businesses and homeowners ever adopted the system, however, largely because of its high initial cost.

Another Laboratory conservation project that received broad media attention was its experiment in bioconversion called ANFLOW. In 1972, Congress mandated secondary sewage treatment for all communities. The Laboratory estimated the new systems would double the energy used for sewage treatment, so it decided to explore technologies that might reduce energy consumption and costs. Alicia Compere and William Griffith of Chemical Technology Division devised a bioreactor, known as ANFLOW, to explore its energy-saving possibilities in treating sewage.

While conventional activated-sludge sewage treatment used aerobic bacteria to digest wastes, the ANFLOW system used anaerobic microorganisms that did not require oxygen. This change eliminated the need for energy-consuming pump aerators, which supplied conventional systems with oxygen. The absence of aerators, in turn, saved the energy consumed to operate the pumps. Moreover, the ANFLOW system could produce methane gas, for use as fuel, from sewage and could recover valuable chemicals from industrial wastes that could be reprocessed and then reused.

On its own, the Laboratory built an experimental ANFLOW bioreactor. In 1976, it contracted with the Norton Company to build a pilot ANFLOW bioreactor to be installed at an Oak Ridge municipal sewage treatment plant. Completed in less than a year, the ANFLOW bioreactor pumped sewage through a fifteen-foot cylinder packed with gelatin-coated particles to which the microorganisms attached themselves. The packing, which could be crushed stone, ceramics, or other particles, facilitated the flow of wastes and provided additional surfaces for the microorganisms, which thrived and reproduced while consuming the wastes.

Richard Genung, Charles Hancher, and Wesley Shumate of Chemical Technology Division managed the ANFLOW program and in 1978 awarded a subcontract for the design of a larger demonstration plant, which was installed as part of the Knoxville sewage treatment system. Potato processors, meat packers, and other industries expressed interest in this efficient waste treatment method. Work on ANFLOW thus enabled the Chemical Technology Division to embark on a broad research agenda into biological solutions for other waste disposal problems.

Municipalities don't build new sewage treatment plants very often. They are capital-intensive, time-consuming projects that may require a decade or more to negotiate and construct. Therefore, energy savings derived from more efficient sewage treatment would be a long time coming.

By contrast, homeowners replace several electric appliances each decade. Believing that aggregate energy savings could be substantial, Laboratory researchers launched detailed studies of ways to improve the efficiency of heat pumps, refrigerators, furnaces, water heaters, and ovens.

Eric Hirst, Robert Hoskins, and colleagues in the Energy Division gained wide acclaim for computer modeling of home appliances to identify opportunities for greater energy efficiency. Their computer analysis of refrigerator designs, for example, indicated that energy use for refrigeration could be halved through better insulation, adding an anti-sweat heater switch, improving compressor efficiency, and increasing condenser and evaporator surface areas.

The Laboratory's energy-saving recommendations for home appliances were incorporated into the design standards of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers and also into experimental appliances designed by subcontractors under the management of Virgil Haynes at the Laboratory. Out of this applied research came more efficient appliances, notably a heat-pump water heater, that were soon manufactured for commercial markets. By the 1980s, most American homes had at least one appliance that was more energy efficient as a result of the Laboratory's conservation research.

FOSSIL ENERGY

With nearly half of the world's known coal reserves, the United States has been called the "Saudi Arabia of coal." In the face of dwindling domestic petroleum supplies, scarce natural gas reserves, and the uncertainty and escalating price of oil imports, it seemed logical in the 1970s to supplement petroleum with fuels produced from coal.

Science had long before shown that applying heat and pressure to coal could produce liquids, gases, and solids for fuel. Efforts to turn scientific theories and blueprints into commercial ventures, however, had been minimal. Then, in 1975, ERDA announced its goal of producing a million barrels of synthetic oil from coal daily by 1985. To produce that much synthetic fuel would require as many as twenty plants, so ERDA contracted with industry to plan and design a series of pilot plants and demonstrations. ERDA's Oak Ridge Operations office managed the contracts and obtained research support from the Laboratory.

In response to this major federal initiative, Murray Rosenthal announced an interagency agreement with the Office of Coal Research that brought the Laboratory into fossil energy research. This agreement culminated in a coal technology program headed by Jere Nichols, later renamed the fossil energy program under Eugene McNeese and budgeted at $20 million annually. It included fundamental studies of the structure of coal, the carcinogenic properties of coal conversion products, a hydrocarbon reactor, and a potassium boiler to improve the efficiency of producing electricity by burning fossil fuels. Under this program, the Laboratory exchanged personnel and collaborated with the Bureau of Mines' coal laboratories at

Bruceton, Pennsylvania; Morgantown, West Virginia; and Laramie, Wyoming.

Planning to fund industrial pilot and demonstration plants that used synthetic refined coal and hydrocarbonization processes, ERDA assigned the Laboratory a major role in evaluating the progress of this broad ranging initiative. For one project, Henry Cochran and colleagues in the Chemistry and Chemical Technology divisions built a model hydrocarbon reactor that mixed finely ground coal with hydrogen under high pressure and temperature to form synthetic oil, plus a substitute for natural gas and a coke-like solid fuel. Modeling experiments identified the optimal combination of pressure and temperature for fuel production. Related projects conducted by Richard Genung, John Mrochek, and their colleagues included studies of coal thermal conductivity, recovery of aluminum and minerals from fly ash, and environmental controls.

A Bioprocess group, led by Charles Scott of the Chemical Technology Division, launched a series of studies of bioreactors. These research efforts coupled engineering with microorganisms for treatment of waste effluents. The dual goal was to concentrate and isolate trace metals and to produce liquid and gaseous fuels organically. In bioreactors somewhat resembling the ANFLOW sewage treatment project, microorganisms adhering to fluidized particles in columns could absorb toxic compounds from the wastes of coal conversion processes.

Researcher Chet Francis in the Environmental Sciences Division demonstrated that simple garden soil bacteria in bioreactors could remove nitrates and trace metals from industrial wastes effluents. As a result, the Laboratory subsequently built a pilot bioreactor used by the Portsmouth, Ohio, gaseous diffusion plant to treat nitrate wastes, and the Y-12 plant used Francis's design for a full scale plant to treat nitric acid wastes.

In the Engineering Technology Division, John Jones's team developed a fluidized-bed coal reactor connected with a closed-cycle gas turbine for power generation. Aiming to make high-sulfur Appalachian coal more environmentally acceptable, the system fed coal and limestone particles into a furnace where jets of preheated air agitated them, igniting the coal and providing the heat needed to combine the limestone with the coal's sulfur dioxide to form harmless gypsum. ERDA sponsored the construction at the Y-12 plant of a prototype to prove that Appalachian coal could be burned cleanly during power generation.

Eugene Hise and Alan Holman devised another method of cleaning sulfur from coal. Because sulfur-bearing iron pyrites and ash-forming minerals are weakly attracted by magnetic fields and coal particles are mildly repelled, they devised a system for magnetically cleaning coal, using a superconducting solenoid to provide a magnetic field of the required shape and force.

In another coal-related research initiative, the National Science Foundation (NSF) funded a regional evaluation of the economics of strip mine reclamation in Appalachia. Robert Honea and Richard Durfee headed a team in 1975 that used satellite imagery, census data, and regional-scale models to analyze strip mining. Focusing on mining in the New River basin north of Oak Ridge, the study took images from space satellites to classify land cover types, which were then verified with aerial photographs. Researchers could examine strip-mining effects during every overhead pass of the satellite, enabling them to obtain a better understanding as the mining unfolded instead of just a snapshot of the impacts once the mining was completed.

In 1975, ERDA Director Seamans broke ground for an Environmental Sciences Laboratory in Oak Ridge, a two-unit structure that became the first such programmatic laboratory in ERDA. The Laboratory's first major laboratory and office expansion since the 1960s, Environmental Sciences was located at the west end of the Laboratory near the Aquatic Ecology Laboratory. The 88,000 square-foot main building was connected by walkways to greenhouses, animal and insect facilities, and chambers for controlled environment experiments.

Chester Richmond, who succeeded James Liverman and John Totter as the associate director for Biomedical and Environmental Sciences, in 1976 implemented a life sciences program at the Laboratory to support coal conversion technologies as mandated in amendments to the synthetic fuel legislation. This program, led by ecologist Carl Gehrs of Environmental Sciences Division, examined the chemical and physical characteristics of coal liquids, their biological and health effects, and their transport through ecosystems, and worked closely with the Environmental Protection Agency. From this program came funding for mutagenesis testing in the Biology Division, ecological toxicology in the Environmental Sciences Division, and health risk effects in the Health and Safety Research Division. These efforts enabled the Laboratory to prove that coal conversion liquids and effluents could be quite toxic and provided information that allowed chemical processing changes to produce less toxic products.

FUSION AND FISSION ENERGY

Under ERDA, the Laboratory's fusion energy research expanded during the 1970s, while traditional fission energy research declined. Although fusion research could not enhance the nation's short-range energy posture, ERDA gave the program substantial support in the hope that it would ultimately provide a long-range solution to the nation's energy problems. With the end of molten salt and high-temperature gas-cooled reactor research in 1976, support for the research agenda of the Laboratory's gray eagles had been reduced to the Clinch River breeder reactor technology and related fuel reprocessing for plutonium recovery.

Under John Clarke, Postma's successor as chief of fusion energy research, successful testing of the ORMAK and ELMO bumpy torus devices continued into the 1970s. The Laboratory also built ISXs--impurities study experimental devices--to illuminate the behavior of impurities inside fusion reactor plasmas. For the impurity study experiments, the Laboratory developed a pellet injection method, firing frozen hydrogen pellets into fusion plasmas to maintain the plasma densities.

Fusion research advances during the ERDA years included the neutral beam technology developed by Bill Morgan's team to heat plasma inside a fusion device. The neutral beam technology brought Oak Ridge's ORMAK and Princeton's tokamak to record temperatures that approached the breakeven point needed for self-sustaining reaction. Investigations of huge superconducting magnets for containing fusion plasmas began under Hugh Long, Martin Lubell, Fred Walstrom, and William Fietz, and led to the selection of the Laboratory in 1977 to build the Large Coil Test Facility. Managed by Paul Haubenreich, this facility would test super-cold magnets, weighing forty tons each, that were manufactured both in the United States and abroad.

Although fusion energy research prospered, the Laboratory built no new nuclear reactors and nuclear energy development declined during the 1970s. The Laboratory in 1976 changed the name of the Reactor Division to Engineering Technology because its work no longer concerned overall reactor design; rather, it focused on the development of engineering systems for both nuclear and nonnuclear facilities.

After 1976, the Laboratory's nuclear energy research focused largely on the Clinch River breeder reactor project and plans to reprocess its fuel. Design of the steam generator and heat exchangers for the Clinch River reactor was undertaken by Laboratory metallurgists led by Peter Patriarca, who investigated thermal stress and creep in the materials to be used in these systems. Even this support program faltered after the election of President Jimmy Carter, who opposed the Clinch River project.

SPLENDID CROWDING

During its urgent energy research for ERDA, the Laboratory expanded. By 1977, it had acquired lead responsibility for five major ERDA programs and had become involved with the full complement of the nation's energy programs. In addition, it had undertaken work for eleven other agencies, amounting to $35 million in funding annually, and it was subcontracting six times the amount of outside work it had supported in 1974. The number of Laboratory personnel rose to more than 5000, performing and supporting some 700 scientific and technical projects. The Laboratory also hosted 1250 guest researchers and more than 25,000 visitors annually.

Although the Environmental Sciences Laboratory and the Holifield Heavy Ion Research Facility were under construction in 1977, the Laboratory had not added significant space to its complex since the 1960s. Existing working space was reduced even more by the addition of mini-computers and copying machines during the 1970s. The stereotype of scientists cogitating in splendid isolation was far from true at the Laboratory in 1977.

In fact, conducting research there had become a close-quartered affair.

"The fact is that programs grow faster than buildings can get built or that money can be found for that purpose," lamented Postma. "In practice, the only justification for new buildings is to alleviate crowded conditions that already exist rather than rationally anticipating projected needs," he elaborated. "Thus, in the future there will be more crowding at the Laboratory, more sharing of offices, and far greater need for understanding and cooperation by all members of the Laboratory."

The problem of overcrowding lessened unexpectedly in 1977 when newly elected President Jimmy Carter and his Department of Energy adopted personnel ceilings that capped the number of Laboratory employees. After four years of nearly nonstop additional hiring, the Laboratory's personnel offices suddenly became tranquil and quiet.

President Carter walked to the White House in January 1977 in the midst of one of the 20th century's coldest winters. At the time, the effects of the 1973 oil crisis still rippled through the national economy. Unprecedented cold temperatures generated unanticipated demands for energy supplies, placing additional stress on an energy system that had not fully adjusted to the post-OPEC energy world. The result was another energy crisis, although not nearly as severe as the paralyzing events that gripped the nation four years before. Nevertheless, during the oil and natural gas shortage, the Laboratory narrowly avoided a complete shutdown for lack of heat only because the K-25 plant shared its oil reserves during the emergency.

Calling for the "moral equivalent of war" on energy problems, President Carter in the spring of 1977 requested public sacrifices for the sake of regaining control of the nation's energy future. To manage the battle, he proposed establishing a cabinet-level Department of Energy. Approved by Congress in August 1977, the new Department of Energy (DOE) absorbed the functions of the ERDA, the Federal Energy Administration, and the Federal Power Commission, plus energy programs from other federal agencies.

Carter appointed James Schlesinger, former AEC chairman and Secretary of Defense, his energy secretary. In addition, the president announced his opposition to the Clinch River breeder reactor project and stopped the reprocessing of nuclear fuel. These decisions clouded the future of nuclear energy which, in turn, placed the future of the Laboratory's nuclear divisions on an uncertain path with no clear signposts pointing the way to the future. For the grey eagles, the breeder was the future. If the project was abandoned, then what?

STABILITY AMID TRANSITION

The transition from ERDA to DOE proved difficult. The ERDA administrator and assistant administrators resigned before DOE became functional in October 1977, leaving agency program direction unclear. "Whereas we perceive uncertainty and lack of clear direction in Washington, the realities at the Laboratory are quite different," observed Alex Zucker during this transition. "Our programs are productive, our staff is busy. Stability rather than uncertainty characterizes our work; and, if we work now in new areas, we are doing it with the old elan."

Secretary Schlesinger revised the system for managing DOE's eight multiprogram laboratories, thirty-two specialized laboratories, and sixteen nuclear materials and weapons laboratories. For their institutional needs, the laboratories were to report to assistant secretaries in Washington instead of regional operations officers. Invited to Washington to advise Schlesinger on basic research needs, Postma declared that integrating energy development into a single department at last recognized that energy was as important as labor, agriculture, and defense. "There will be studies galore to evaluate everything," Postma warned. He was, however, confident that the Laboratory would prosper despite the "turbulence represented by the changing political and programmatic winds in Washington."

During 1978, the transition to DOE was completed. Believing that national laboratories had reached optimum size, the Carter administration sought to work more directly with industry, expanding the role of national laboratories as program and subcontract managers. It designated national laboratories as centers of excellence in special fields and imposed ceilings on the number of personnel. Oak Ridge was appointed the lead laboratory for coal technology and fuel reprocessing, and the Laboratory was told that its staff could not exceed 5165 personnel for 1979.

The Carter administration proved more interested in energy conservation and "soft" energy than in nuclear energy. Taking its cues from Washington, the Laboratory began to emphasize small programs in geothermal and solar energy initiated under ERDA.

John Michel managed the Laboratory's research on geothermal energy using hot water and gases at or below the surface. This included research in the Chemistry Division on scaling and brine chemistry, in the Metals and Ceramics Division on corrosion, and in the Engineering Technology and Energy divisions on cold-vapor, low-temperature heat cycles with the goal of improving the efficiency of geothermal energy. A related research program studied ways to improve heat exchangers to capture the oceans' thermal energy. Rather than burning the rocks and boiling the seas with nuclear energy--a dream of the 1960s--this research sought to extract low-level energy from the Earth and ocean in kinder and gentler ways.

The Laboratory's solar energy research was circumscribed by formation of a special DOE laboratory, the Solar Energy Research Institute in Colorado. Robert Pearlstein became coordinator of Oak Ridge's small solar program, which included fruitful research in the Chemistry and Solid State divisions. The Chemistry and Chemical Technology divisions investigated the production of hydrogen from water by using green plant materials to capture and convert the sun's energy catalytically, while the Solid State Division investigated improved photovoltaic solar cells for converting sunlight directly into power.

Funded initially as a seed money project, John Cleland's team in the Solid State Division developed a new method of doping silicon to produce the semiconductors used in solar cells. Instead of using chemical doping methods, silicon was inserted in the bulk shielding reactor to transmute a silicon isotope into phosphorus through interacting with neutrons. This process provided uniform distribution of phosphorus in the silicon, thereby improving the cell efficiency of solar cells fabricated from this material.

In a related development, the Solid State Division in 1978 used pulsed lasers in preparing silicon for solar cell fabrication. A dopant such as boron was deposited on a silicon surface, or implanted onto the surface to provide good distribution within the silicon. Lasers also were used for annealing semiconductors to remove crystal imperfections introduced in the implantation process. Private manufacturers soon found a number of commerical application for these techniques.

ALMOST A MECCA

To observe firsthand the Laboratory's research achievements and to soothe the Laboratory's ill feelings generated by his decision to oppose the Clinch River breeder reactor project, President Carter visited Oak Ridge in May 1978 at the request of Senator James Sasser. The president brought his science advisor and energy staff with him. Remembering his service as an officer in Admiral Rickover's nuclear navy, Carter declared, "Oak Ridge was almost like Mecca for us because this is where the basic work was done that, first of all, contributed to the freedom of the world and ended the war and, secondly, shifted very rapidly to peaceful use of nuclear power."

The first president to visit the Laboratory while in office, Carter received a cordial, informative welcome. In the 4500N lobby, Postma introduced him to Charles Scott, who described bioreactor experiments; Samuel Hurst, who discussed lasers that detected single atoms among millions; and John Jones, who explained a fluidized-bed coal burner designed to cogenerate power and heat. Afterwards, the president enjoyed technical presentations and a roundtable discussion with five scientists in the auditorium.

The president seemed particularly interested in Lee Berry's description of fusion research, asking how it compared with Soviet research. Berry responded that the United States may have enjoyed a slight lead in the fusion race. Sandy McLaughlin appealed to the president's environmental interests by describing

Laboratory research on the ecological effects of atmospheric pollutants.

For security reasons, Carter was unavailable to the public during his visit. The Laboratory personnel who greeted the president at his entrance politely cheered him, surprising local reporters who thought that the president's opposition to the Clinch River reactor and subsequent political decision to move the centrifuge plant from Oak Ridge to Ohio would elicit a cold though polite silence, and perhaps even murmurs of discontent.

President Carter, however, was near the peak of his popularity at the time of his visit to the Laboratory. Afterwards, untoward events plagued his administration, exacerbating the national energy crisis and inevitably affecting the activities of the Laboratory.

QUICK RESPONSES

The March 1979 accident at Three Mile Island Unit 2 surprised nuclear experts at the Laboratory and elsewhere. Although nuclear safety research had concentrated on the risks of rupture and the possibility of loss of coolant accidents in light water reactors, the Three Mile Island accident in Pennsylvania came instead when a pressure valve stuck and inaccurate instrumentation and human error complicated the emergency. Having a national reputation in the safety field, Laboratory staff became immersed in the Three Mile Island emergency and subsequent analysis.

When the company owning the disabled reactor called Floyd Culler at the Electric Power Research Institute for help, Culler (who had just left the Laboratory after 25 years of service, including one year as acting Director) contacted Postma and other Laboratory officials, as did the staff of the Nuclear Regulatory Commission. During the emergency, Laboratory personnel served as consultants and on-site analysts. Seventy-five staff members performed technical and analytical research during the emergency, or provided information to the committee appointed by President Carter to investigate the accident.

The Laboratory helped the industry recover from the accident in many ways. An Industrial Safety and Applied Health Physics Division team led by Roy Clark monitored the radiation, while Robert Brooksbank's team minimized radioactive iodine releases by adding chemicals to the cooling system and by arranging replacement of the filters used to cleanse reactor gases before their release into the atmosphere. The absence of widespread iodine releases was in part a testament to their success.

The Chemical Technology Division designed systems to store the contaminated water and remove the fission products. Robert Kryter and Dwayne Frye of the Instrumentation and Controls Division supervised the installation of monitors that replaced the damaged sensing systems inside the reactors. Wilbur "Dub" Shults and an Analytical Chemistry team analyzed samples from the accident site, to assess the severity of contamination and devise clean-up strategies. Mario Fontana's Engineering Technology group and David Hobson's Metals and Ceramics team examined core cooling and debris, zircalloy cladding damage, hydrogen generation, and fission product releases. David Bartine's group from Engineering Physics and Computer Sciences addressed radiation and shielding issues. Joel Buchanan led the team studying the hydrogen in the reactor, and David Thomas supervised an Engineering Technology Division group that fabricated an electrical core to simulate the accident in the thermal-hydraulic test facility.

Accident investigations and recovery activities continued for years, and the Laboratory took pride in its emergency response. Especially fruitful was the review by Anthony Malinauskas and David Campbell of the issues surrounding radioactive iodine releases for President Carter's commission and the Nuclear Regulatory Commission.

The accident at Three Mile Island forever changed the public's attitude toward nuclear power. The Laboratory's response, however, helped provide a sound scientific base for understanding the causes and effects of the most serious mishap in the history of the U.S. commercial nuclear industry.

Later in 1979, the nation and the Laboratory became troubled by the revolution in Iran and the hostage and energy crises that ensued. Visiting Iran shortly before the revolution to discuss training Iranian technicians at the Laboratory, the associate director for nuclear power and reactor engineering, Donald

Trauger, observed firsthand the political instability there. He refused, however, to describe the subsequent acute petroleum shortage as another energy crisis. After a decade of energy crises, he believed that it was time for the nation and world to accept the shortages of adequate energy supplies as a chronic problem. "Crises" suggest unexpected situations that can be set straight by rapid, aggressive responses. Instead, Trauger suggested that "we must hurry to find solutions, but we must not become overly impatient in our quest."

Laboratory energy conservation efforts accelerated during the Iranian embargo. The Laboratory converted its steam power plants from natural gas and petroleum fuel back to coal and turned to gasohol to fuel its vehicles. It could not, however, find a local gasohol supplier and had to use its own staff to mix gasoline with ethanol. In addition, the Laboratory's environmental impacts group was commandeered to analyze implementation of the Strategic Petroleum Reserve--a federally-sponsored effort to store large quantities of oil that could be tapped in times of emergency. The Strategic Petroleum Reserve later would serve an important role in stabilizing oil prices during the Persian Gulf War of 1991.

CONSTANCY OF CHANGE

In 1980, the Laboratory found itself caught in the impasse between Congress and President Carter over the Clinch River breeder reactor project. Funding for the Laboratory's breeder research to support the reactor and fuel reprocessing was slashed significantly--a blow to fission research that further discouraged the Laboratory's dwindling number of charter members.

"This last defeat has convinced gray eagles like myself that the rainbow we have been following for the past 30 years may indeed not have the long sought after pot of gold at the end," lamented Peter Patriarca, head of the Laboratory's breeder reactor materials research program. "I feel that I and others like me have accomplished a lot in 30 years of service," he concluded, "but we really haven't achieved the ultimate and that is my disappointment."

Still, 1980 was a banner year for many Laboratory programs. For the first time, the budget exceeded $300 million. Of this total, $20 million was subcontracted to universities and $60 million to industry to support research and engineering. Completed in 1979, the new Environmental Sciences Laboratory eased staff crowding. Equally important, three new user facilities opened in 1980, marking the culmination of three successful programs launched in the 1970s: the National Environmental Research Park, Holifield Heavy Ion Research Facility, and National Center for Small-Angle Scattering Research.

The Oak Ridge National Environmental Research Park, comprising 12,400 acres of protected land for environmental science research and education, opened in 1980 as the fifth outdoor laboratory of the Department of Energy. Nearly surrounding the Laboratory, it made up about a third of the Oak Ridge reservation. Here, scientists inventoried plant and animal species; monitored the dynamics behind climate and ecological change; undertook studies of contaminant transport and bioremediation; and cooperated with local, regional, and private agencies to promote science and environmental education. The Walker Branch Watershed in the park emerged as a key experimental facility for biogeochemical and hydrologic research.

One early research effort in the park tested bird and small animal habitat models later used by the Army Corps of Engineers to prepare environmental impact statements for construction projects. Another early research effort examined atmospheric deposition of pollutants for the National Oceanic and Atmospheric Turbulence and Diffusion Laboratory located in Oak Ridge.

Former Congressman Chet Holifield participated in the December 1980 dedication of the heavy ion research facility bearing his name. "One more curiosity of the scientifically oriented human mind," was Holifield's description of the awesome tower and the pelletron accelerator it housed.

Twice as powerful as any machine of its type, the accelerator in the tower was coupled with the Oak Ridge isochronous cyclotron to convert heavy ions into high speed projectiles. Colliding with targets, these projectiles produced amazing results valuable to fundamental nuclear science. Laymen were more amazed by the spin spectrometer, a clustered array of gamma ray detectors, dubbed a "crystal ball," to measure the energy of the excited, rotating products of the heavy ion collisions.

Like the environmental park, the heavy ion facility was designed to be a national user facility. To host visiting researchers, it included nearby the Joint Institute for Heavy Ion Research. A result of the Laboratory's partnership with Vanderbilt University and the University of Tennessee, the institute was an energy-efficient, mostly underground, structure designed by Hanna Shapira of the Laboratory staff to temporarily house visiting researchers from outside Oak Ridge. In a sense, it became a monument to the Laboratory's energy conservation programs of the 1970s.

The National Center for Small-Angle Scattering Research was the Laboratory's third user facility opened in 1980. Small-angle neutron scattering blossomed during the 1970s as a way to explore biological, chemical, and physical materials with important microscopic dimensions of 10 to 100 angstroms. Although two laboratories using this scientific technique existed in the United States, they were not readily available to independent researchers, and in 1977 the National Science Foundation (NSF) proposed to fund a center for use by scientists from all organizations. Wallace Koehler and Robert Hendricks submitted a proposal to establish a user-oriented, small-angle scattering center at the Laboratory, including a new small-angle neutron scattering (SANS) facility at the high-flux isotope reactor along with access to the Laboratory's existing small-angle x-ray and neutron scattering devices. Their competitive proposal, which received NSF approval in 1978, also included computer equipment that allowed users the luxury of largely automated experimentation.

The new SANS facility opened in 1980 at the high-flux isotope reactor and included a detector designed by Casimir Borkowski and Manfred Kopp. Directed by Koehler and Hendricks, the facility compared well with the best facilities in Europe, and the center offered a combination of x-ray and neutron scattering that made the Laboratory a mecca for this type of materials research.

With these new facilities, the Laboratory entered the 1980s prepared for its role as a user-oriented institution that could host scientists from around the world. After a decade of energy crises and constant transition, the Laboratory seemed to have adjusted well to its new role as a multiprogram laboratory of the Department of Energy (DOE).

During the presidential election of late 1980, however, candidate Ronald Reagan complained that the DOE had not produced a single additional barrel of oil and promised to dismantle Carter's creation. By Christmas of that year, Reagan's transition team announced it had profound changes in mind for both DOE and its national laboratories.

In less than a month, they would have an opportunity to put those ideas into practice. Barely having caught its breath from a decade of whirlwind change in energy policy and direction, the Laboratory was poised for yet another transition. The Reagan years were about to begin.

CHAPTER VIII

THE MULTIPROGRAM LABORATORY

In the 1970s, the Laboratory moved beyond its war-rooted preoccupation with nuclear power to research fields embracing all energy forms. By the early 1980s, that journey was complete. In the words of Associate Director Alex Zucker, Oak Ridge had become "a multiprogram research and development laboratory having a variety of energy-related missions of national importance."

Emphasis on the Laboratory's multiprogram character was in part a response to the "Reagan revolution" of the 1980s, when fierce debates arose over the proper balance between the public and private sectors. The Reagan administration, in fact, proposed to abolish DOE and severely curtail the activities of the national laboratories. Energy policies, the administration stridently proclaimed, should be shaped by the private sector. If government had any role at all, it should be narrowly confined to questions of basic research.

President Reagan appointed James Edwards, a former governor of South Carolina and oral surgeon with little background in energy policy, to preside over DOE's dissolution as the nation's "last" Secretary of Energy. The president also laid off thousands of DOE employees and sought to transfer its residual functions to the Department of the Interior under James Watt or the Department of Commerce under Malcolm Baldrige.

Aiming for major reductions in the public sector, in 1981 the Reagan administration initiated executive reviews of most federal agencies, including DOE laboratories. Kenneth Davis, Deputy Secretary of Energy under Edwards, directed an Energy Research Advisory Board to survey the laboratories' work. Congress conducted similar investigations.

Investigators distinguished between three kinds of laboratories: single-purpose specialty, purely weapons, and broadly diverse multiprogram laboratories. Oak Ridge, Argonne, and Brookhaven were the original multiprogram laboratories, but the list expanded to include more than a dozen DOE laboratories.

Vocal criticisms of these multiprogram laboratories arose from universities, consulting firms, and industrial laboratories. Because of the laboratories' excursions during the 1970s into diverse energy research agendas, critics saw them as subsidized competition. One industrial executive, for example, charged: "When I find Oak Ridge planting trees to see if they can't grow them a little closer together and faster, which the paper companies could do; testing solar cells that there are 300 companies already set up to test; and so on, I just wonder if we haven't lost our sense of focus altogether."

Admitting the missions of national laboratories had become diffuse and perhaps "unfocused" during the 1970s, Laboratory leaders asked whether more precise definitions of the roles of all laboratories--national, private, and university--would help clarify the situation and foster a healthier and more robust national research program. Truman Anderson, chief of Laboratory planning and analysis, urged that national laboratories should "assume a broader role in a new partnership with industry and universities." This new partnership was to keynote Laboratory activities throughout the 1980s and into the 1990s.

Program diversity enabled the Laboratory to weather the intense scrutiny of 1981; so, too, did the administration's pronuclear stance, which ameliorated its initially harsh approach to government-sponsored energy programs. Commenting on the effects of Reagan's policies after his first year in office, Laboratory Director Herman Postma declared: "The impacts...so far, while unwelcome and frequently painful, have been rather moderate overall, and certainly less severe than at many of our sister laboratories." Indeed, Postma thought the Reagan policies may have had some salutary effects, notably in restoring an equitable balance between basic science and applied technology.

About 700 Laboratory personnel were let go during the early 1980s as a consequence of Reagan administration cost-cutting measures. However, the Laboratory's multiprogram character, together with its connection through Union Carbide to the Y-12 and K-25 plants, allowed the cuts to be handled largely by transferring personnel and not filling positions when people retired or resigned.

The first year of the Reagan revolution would prove the most unsettling for the Laboratory. Deep recession in 1982 and growing federal budget deficits soon fostered less hostile views of Laboratory activities within the administration. A national consensus emerged that viewed scientific and technological innovations as the nation's "ace in the hole" for breaking the cycle of budget deficits, high unemployment, and unfavorable trade balances. In 1982, Herman Postma observed that support was building in government for concerted efforts to "encourage high-technology development as the best hope for the nation's economic future."

The Reagan administration's respect for nuclear power didn't hurt either. In fact, it was the melding of the Laboratory's long-standing expertise in nuclear power with its new-found strength in technology transfer that not only helped it overcome the administration's policy blitzkrieg, but enabled Oak Ridge to eventually thrive and prosper.

Along with other DOE laboratories, Oak Ridge endured the loss or retrenchment of some programs and staffing cuts of several hundred personnel yearly during the early 1980s but emerged in a stronger position later in the decade. In time, the Reagan administration abandoned efforts to dispense with DOE, as well, in part because of congressional opposition, in part because of the heavy weight of bureaucratic inertia, and in part because DOE laboratories emerged as critical research centers for the Reagan-inspired strategic defense initiative.

Thus the Reagan administration's strenuous reform efforts did not seriously sap the overall strength of the Laboratory. These efforts, however, did rearrange Laboratory priorities and programs. For example, Reagan policies forced the Laboratory to shut down its fossil energy program and scale back its energy conservation program. When the administration terminated the synthetic fuel program in favor of supply-side, market-driven energy initiatives, funding for the Laboratory's coal research dwindled. To maximize the return on its diminished resources, DOE decided to conduct all its coal research in laboratories formerly linked to the Bureau of Mines. Although the administration also looked unfavorably on energy conservation, the Laboratory's energy conservation program survived an early round of cuts and rebounded to eventually enjoy renewed vigor.

STAR WARS

In March 1983, President Reagan espoused an antimissile defense initiative that aimed to break the nuclear stalemate by shifting the battlefield to outer space where an impenetrable defense umbrella would forever protect the United States from nuclear attack. Declaring that the strategic defense initiative would make nuclear weapons obsolete by rendering an attack futile, the president proclaimed that the proposal held promise for "changing the course of human history."

Critics dubbed the initiative "star wars"--a flight of fancy charted by an ill-informed president that falsely promised to turn the world's fiercest technological force into its most reliable sentinel of peace.

In truth, scientific opinion was deeply divided on the long-term prospects of this proposal. Beyond the huge price tag, however, one thing was certain. Devising space satellites capable of destroying nuclear missiles would require major scientific and technological advances. Resources at the DOE's national laboratories--both in skilled personnel and sophisticated equipment--would be vital to any chance for success.

Managed by David Bartine, the Laboratory's star wars research agenda, which was set by the Department of Defense, focused on three areas: reactor designs to power space satellites and particle and laser beams; flywheels for energy storage and pulsed power; and particle beams to destroy missiles from space. Studies of highly focused beams of hydrogen particles, able to destroy the electronics of a missile, evolved from the Laboratory's fusion energy research, where beams of neutral hydrogen atoms heated plasmas to high temperatures.

John Moyers headed a team from Engineering Technology and other divisions for the design of a nuclear reactor to provide power bursts for the lasers and weapons aboard space vehicles. Their concept centered on the use of a boiling potassium reactor, perhaps with flywheels for energy storage. Even if never needed for national defense, the reactor might power long-distance space exploration to Mars and beyond.

Although some star wars research was classified, two of the Laboratory's announced achievements included powerful particle beams and mirrors for surveillance satellites. Taking advantage of the negative-ion sources developed in the course of fusion energy research, Laboratory scientists devised the "world's highest simultaneous current density output and pulse length," meaning a particle beam that did not spread out for thousands of miles (think of a spotlight instead of floodlight). In cooperation with scientists from K-25, Y-12, and industry, the Laboratory also conducted research on beryllium mirrors and windows that would permit space satellites to sense the heat of missile launches on Earth. These mirrors and windows were devised, fabricated, and polished in Oak Ridge in cooperation with Martin Marietta Aerospace of Denver.

Star wars research proved equally challenging and did not entirely cease with the end of the Cold War. The Bush administration continued to support the initiative as a key defense measure despite the new world order. Scientific proponents contended that star wars would not only protect the United States (and perhaps the world) from unprovoked terrorist attacks, but could lead to yet unknown and untold applications beyond military defense.

The media seemed more interested in the Laboratory's killer bees research than its star wars work. Newspaper journalists and television reporters enjoyed reporting Laboratory efforts to detect the migration patterns of the Africanized bees, dubbed killer bees, that moved north from Central America during the 1980s, posing a threat to national honey production.

Howard Kerr, an experienced beekeeper working at the Laboratory, became interested in finding ways to detect and track the movements of killer bees. He and his colleagues considered tracking them with radioisotopes, spotting them with infrared devices, or identifying their buzzing with acoustical devices. This would provide scientists with opportunities to disrupt the bees' mating patterns. To Kerr and his colleagues, the threat that killer bees posed to honey production in North America was a serious matter; their research continued as the bees migrated across the Rio Grande into Texas during the 1990s.

ENERGY SYSTEMS

In 1982, the Laboratory spruced itself up for the Knoxville World's Fair, building a visitor's overlook on a nearby hill and opening some facilities to tell crowds attending the fair and nearby attractions about scientific energy research taking place at Oak Ridge's national multiprogram laboratory. The Laboratory also became an anchor for a proposed technology corridor championed by Tennessee Governor Lamar Alexander.

The corridor was built along Pellissipi Parkway, a highway linking west Knoxville to Oak Ridge. The aim of the corridor was to promote regional economic growth, partially through the transfer of Oak Ridge's publicly funded technology to private industries. It was hoped that Pellissipi Parkway, in time, would feature tree-lined industrial parks and glass-encased offices built to market the region's scientific and technological advances. In effect, corridor advocates were seeking to create a Silicon Valley or Research Triangle Park in East Tennessee that would draw on the complementary skills of the region's three major institutions--Oak Ridge National Laboratory, the University of Tennessee, and the Tennessee Valley Authority.

As the World's Fair celebration began, the Laboratory was shocked by news that Union Carbide, after nearly forty years (thirty-four years at the Laboratory) would withdraw as the operating contractor. Three days after the World's Fair opened in May 1982, Union Carbide management announced that the company would relinquish its contract for operating the Laboratory and other Nuclear Division facilities in Oak Ridge and Paducah, Kentucky, although it agreed to serve until DOE selected a new contractor. The terse announcement read by Roger Hibbs of Union Carbide said the decision not to renew the contract resulted from the company's strategy of "concentrating its resources and management attention on commercial businesses in which it has achieved a leadership position. The corporation has no other defense-related operations."

Seventy organizations, ranging from Goodyear, Boeing, Westinghouse, Bechtel, and the University of Tennessee down to small firms, expressed an initial interest in succeeding Union Carbide. After careful consideration, DOE decided to keep the Oak Ridge and Paducah facilities under a single contractor. A year after Union Carbide's decision, DOE requested proposals for operating the Laboratory and the other facilities, and late in 1983 it received formal responses from a half dozen corporations and companies. It narrowed the field to three--Westinghouse, Rockwell, and Martin Marietta. In December, it accepted the proposal of Martin Marietta Energy Systems, part of the Martin Marietta Corporation, known nationally for its defense and aerospace work.

Martin Marietta Corporation was formed in 1961 by the merger of Glenn Martin's aircraft company with Grover Hermann's American-Marietta Company. Aircraft pioneer Glenn Martin, a partner with Wilbur Wright, built bombers for the Army during World War I; later, his firm built such famous aircraft as the China Clipper and the Enola Gay. Grover Hermann, an entrepreneur from Marietta, Ohio, had organized one of the first industrial conglomerates in the United States. Known best for its defense and aerospace contract projects, Martin Marietta Corporation also produced aluminum and construction materials and supervised government-sponsored defense, space, and communications initiatives. Its corporate headquarters in Bethesda, Maryland, supervised its five operating companies employing 40,000 at 128 sites throughout the nation. In 1984, Martin Marietta Corporation had major contracts for the space shuttle and MX missile designs and research laboratories located in Denver, Orlando, and Baltimore. To administer the Laboratory and the other Oak Ridge and Paducah facilities, it formed a subsidiary called Energy Systems, Incorporated.

To the relief of Laboratory management and personnel, the transition from Union Carbide to Energy Systems began in January 1984 and proceeded on schedule with minimal impact on Laboratory staff or activities. In April 1984, Energy Systems took full responsibility for Laboratory operations along with the K-25 and Y-12 facilities in Oak Ridge and the Paducah gaseous diffusion plant in Kentucky. Later, DOE added the Portsmouth, Ohio, enrichment facilities to the Martin Marietta operations contract.

Although day-to-day operations remained much the same, the change in administration brought new long-term directions for the Laboratory. Martin Marietta Energy Systems was the first contractor-operator at the Laboratory without a chemical engineering background; its roots lay in prompt delivery of high-quality technology under contract with government and other agencies. Its agreement with DOE for operating the Laboratory, moreover, contained innovative provisions, including reinvesting a percentage of its annual fee as venture capital in Oak Ridge, developing an Oak Ridge technology center, and pursuing an aggressive technology transfer program.

For the first time at any of DOE's multiprogram laboratories, an award fee was to be paid to the contractor operator, Energy Systems, for its management of the facilities. Beyond a base sum for basic operations, Energy Systems' fee was to be determined by the quality of its performance, judged by DOE every six months. "This performance-based fee is designed to reward a contractor's initiative, efficiency, and effectiveness in both programmatic and administrative tasks," commented Herman Postma, adding that he thought the fee would emphasize the highest quality and creativity in research and development. Some scientists thought the fee a disincentive, however, because of the difficulty that Energy Systems and DOE would have in calculating the productivity of the Laboratory's research efforts.

To accelerate spinoff of Oak Ridge technology to industry, Energy Systems proposed to license DOE patent rights for technologies developed at the Laboratory. In 1985, DOE approved this proposal. Energy Systems could now license to different companies the exclusive right to manufacture specific products or provide specific services based on the science and technology developed at the Laboratory. In return, the companies would pay royalties or license fees to Energy Systems, which in turn would be reinvested in product refinement, prototype production, royalty shares for inventors, university programs, or other technology transfer activities. This initiative was in accord with President Reagan's policies encouraging private sector growth and economic development through the transfer of valuable scientific findings to the world of commerce.

MANAGEMENT CHALLENGES

At the time of the 1984 transition, Director Postma had four associate directors administering technical activities. Donald Trauger oversaw nuclear and engineering technologies, including the Chemical Technology, Engineering Technology, Fuel Recycle, and Instrumentation and Controls divisions together with the

Laboratory's nuclear reactor, fuel reprocessing, safety, and waste management programs. Murray Rosenthal supervised the Laboratory's advanced energy systems programs including the Energy and Fusion Energy divisions, along with the conservation, fossil energy, and fusion programs. Alex Zucker administered the physical sciences including the Physics, Chemistry, Analytical Chemistry, Solid State, Engineering Physics and Mathematics, and Metals and Ceramics divisions. Chester Richmond had purview over the biomedical and environmental sciences, with the Biology, Environmental Sciences, and Health and Safety Research divisions; the Information Center complex also was assigned to him. The support and services divisions reported to the executive director, Kenneth Sommerfeld.

BIOMEDICAL AND ENVIRONMENTAL SCIENCES

The Laboratory's biomedical and environmental sciences programs may have had the most direct influence on American life during the 1980s; at least, their environmental and health foci dominated the national news media during the decade. In keeping with trends at DOE, as the Laboratory's energy technology focus diminished, it turned to major national environmental and health issues, and as funding for applied research increased, those divisions capable of providing it thrived. As a result, the Laboratory's Environmental Sciences Division directed by Stanley Auerbach and later David Reichle and its Health and Safety

Research Division directed by Stephen Kaye flourished. By the end of the 1980s, about a quarter of the Laboratory's program lay in the environmental and health fields.

The Laboratory's basic ecological research continued to concentrate on the processes by which contaminants moved through the environment and on identifying the ecological effects of energy production. With the National Environmental Research Park opened as an outdoor laboratory in 1980, studies of Southern and Appalachian regional ecosystems continued. The Laboratory also expanded its hydrologic and geochemical expertise in support of DOE waste management programs, to examine the effects of waste on the environment.

The Laboratory's study of indoor air pollution, started in 1983 by members of the Health and Safety Research Division for the Consumer Product Safety Commission, may have received the most media attention. A Laboratory survey found that newer homes with tighter construction and improved insulation suffered air pollution from substances such as formaldehyde and radon. Of special concern was radon gas, a decay product of natural uranium in the ground that seeped upward and concentrated in the more tightly sealed homes. If inhaled, it was considered a potential cause of lung cancer. Manufacturers soon were selling radon detection kits to homeowners and urging them to vent the gas from their homes if the levels of indoor radon exceeded government guidelines.

Risk assessment, whose practitioners analyzed the potential risks posed by energy technologies and industrial processes, emerged as an important field within the Laboratory. Such assessment involved extensive use of computer modeling, laser optics, and advanced instrumentation to detect and examine the impacts of energy- and chemical-related compounds on ecosystems. Much of this work concentrated on specific chemicals cited by the Environmental Protection Agency as being potential agents of contamination.

The ecological challenges presented to the Laboratory during the 1980s extended from the region and nation to the world beyond. Biomedically, long-term studies of carcinogenesis, mutagenesis, and other damages to biological systems continued with major support from the National Cancer Institute and other institutes of the Department of Health and Human Services.

Within the Biology Division, research changed dramatically during the 1980s as a result of the advent of genetic engineering and recombinant DNA technology. Biologists learned to alter genes as simply as they had combined and separated chemicals in earlier times. This expanding capability permitted them to characterize cancer-causing genes, clarify the mechanisms for regulating genes, produce scarce proteins for studies, and design new proteins. Major Laboratory research initiatives included basic studies of proteins and nucleic acids, together with the mechanisms of DNA repair, DNA replication, and protein synthesis, which relate to the response of biological systems to environmental stresses.

As funding for basic sciences declined in the face of advances for applied sciences, the number of Biology Division researchers shrank during the 1980s to less than half the number employed during the 1960s. It retained a distinguished staff, however, including seventeen Laboratory biologists elected to the National Academy of Sciences.

The Laboratory's emphasis on the production, development, and use of radiopharmaceuticals contributed to improved public health in several ways during the 1980s. F.F. Knapp's nuclear medicine group in the Health and Safety Research Division made news by developing new radioactive imaging agents for medical scanning diagnosis of heart disease, adrenal disorders, strokes, and brain tumors. Stable isotopes, produced in calutrons in the Chemical Technology Division, were converted into radioisotopes to provide the tracing material for millions of heart scans, which contributed substantially to national health care. By the end of the 1980s, DOE estimated that nearly 100 million Americans annually received improved diagnosis or treatment partly as a result of medical isotope research and production at the Laboratory and other DOE facilities.

Another medical advance arose from work at the Solid State Division's surface modification and characterization center, a user facility headed by Bill R. Appleton and C.W. "Woody" White. Here, ion-beam and pulsed-laser techniques were used to improve the properties of materials, such as harder surfaces with greater resistance to wear and corrosion and better electrical properties. Applied initially to such semiconducting materials as silicon for solar cells, these techniques later proved helpful in the development of new materials such as surgical alloys.

Each year, for example, thousands of patients had been fitted with artificial hip joints made of a titanium alloy. Body fluids, however, caused corrosion and wear that required replacement of the devices after about ten years. At the Laboratory, James Williams and associates implanted nitrogen ions into the titanium alloy to modify it. This made the artificial joints more resistant to the wear and corrosive action of body fluids, thereby significantly increasing the lifetime of such joints. This process was incorporated into a new medical products line that was marketed by Johnson and Johnson Corporation.

New devices in the Biology and Health and Safety Research divisions made possible the imaging of single atoms and of DNA strands during the 1980s. Scanning tunneling microscopes, developed in 1980 and first used for research on semiconductor surfaces, were built at the Laboratory during the decade. These microscopes, which gave new meaning to the word microscopic, could image supercoiled DNA molecules, showing structural changes and the binding of proteins and substances to the strands. Operated by David Allison, Bruce Warmack, and Thomas Ferrell, the new electron and photon microscopes promised to assist in mapping the locations and determining the sequences of genes in DNA, opening new frontiers in biological research.

A team of Environmental Sciences and Chemical Technology researchers sought to use microorganisms in bioreactors to rid the environment of PCBs and other toxic wastes. Experiments along Bear Creek in Oak Ridge indicated that aerating and watering PCB-contaminated soil encouraged the growth of microorganisms that could digest PCBs and convert them into less toxic substances. This success led to additional investigations into bacterial capabilities for digesting and converting other toxic materials.

For many years, researchers in the Health and Safety Research Division analyzed the accuracy of personnel dosimeters for the Laboratory and outside agencies. Other agencies mailed dosimeters to the Laboratory, and the devices were checked by exposure to measured radiation at the health physics research reactor. In 1989, the Laboratory opened a radiation calibration laboratory for checking dosimeters, radiobiological experiments, and related purposes. This laboratory helped fill the research needs stymied by closure of the health physics research reactor.

ADVANCED ENERGY SYSTEMS

Murray Rosenthal's advanced energy systems directorate, including the fossil energy, conservation, and fusion programs, suffered loss of program support during the early Reagan years. Relying on supply-side economics and market forces to meet energy demands, the Reagan administration dispensed with most of the fossil energy program, severely curbing fossil energy research at the Laboratory.

As for energy conservation, so popular during the Carter administration, one official of the Reagan administration declared that it simply meant "being too hot in the summer and too cold in the winter," and contended that increasing energy prices would provide the only incentive needed for conservation. The administration initially mandated major cuts in conservation research funding, forcing the abrupt termination of some energy conservation projects at the Laboratory. Congress, however, restored some of the budget reductions, and the Laboratory's conservation program flourished again during Reagan's second term.

Studies of improved building insulation for energy conservation continued, culminating in 1985 with the creation of a Roof Research Center in the Energy Division in 1985. A cooperative effort by DOE and the building industry, this center tested heat transfer through roofing structures, assessed how these structures reflected or absorbed solar energy, and projected how long they would last. In climate simulation facilities, composite roof segments were instrumented and tested, providing data for the computer modeling of roofing designs. This unique industrial user facility, guided by representatives of roofing manufacturers, researchers, and consumers, added a large climate simulator in 1987 to test roofing under controlled weather conditions. Directed by Paul Shipp and Jeff Christian, the roofing research identified significant convective heat losses in common blown attic insulation and worked with the building insulation industry to devise more effective systems.

In cooperation with the National Bureau of Standards and industry, Laboratory studies of improved home appliances produced significant results as well, notably in the development of absorption heat pumps for heating and cooling that could be powered with natural gas instead of electricity. The Energy Division's Michael Kuliasha and Robert DeVault managed subcontracts with industrial firms to improve and commercialize these heat pumps. Thanks to these and other innovative ventures, the Laboratory's conservation and renewable energy program recovered its losses; in fact, its annual budget rose from $17 million at the start of the decade to $43 million by 1988.

PHYSICAL SCIENCES

The Laboratory's physical science research efforts, under the direction of Alex Zucker, focused on nuclear physics, chemistry, and materials science, utilizing the Holifield Heavy Ion Research Facility, neutron scattering facilities at the high-flux isotope reactor, the surface modification and characterization laboratory, and other user facilities. Zucker also hoped his group would become instrumental in pushing the boundaries of the material sciences through a new High

Temperature Materials Laboratory housing modern equipment for testing the properties of materials needed in high temperature applications. The keynote of this program was the development of existing and new user facilities in partnership with industry and universities.

Although basic research on the chemistry of coal and solvent extraction continued at the Laboratory, the loss of most of the fossil energy program took several divisions into the field of bioconversion as a potential source of energy and improved waste disposal management. Bioconversion research sought to use microorganisms to convert organic materials--sewage, solid wastes, woody biomass, coal, or corn--into fuels. Rather than liquefying coal with heat and pressure, for example, Charles Scott and teams in the Chemical Technology Division turned to accomplishing this in bioreactors in which microorganisms converted coal to liquids. In another case, the Laboratory cooperated with the A.E. Staley Corporation, a corn products company with a plant near Loudon, Tennessee, to improve the fermentation of corn with a fluidized-bed bioreactor in which bacteria converted almost all the sugar in corn into ethanol, used as a petroleum substitute.

Materials research rose to the forefront of the Laboratory's physical sciences during the 1980s. The Laboratory had been a pioneer in alloy development, high-temperature materials, surface modification technology, specialized ceramics, and the development of composite materials. This placed it in an enviable position for contributing directly to industrial technology applications. Welding science can serve to illustrate.

In the nuclear power industry, proper welding was as critical to safety as it was in most other industries--perhaps even more so. The Welding and Brazing group established at the Laboratory in 1950, therefore, had many opportunities to improve welding technology and gained worldwide recognition for its contributions.

National energy production has been hampered when poor welds shut down nuclear powerplants, coal-fired plants, and petroleum refineries. In 1985, when Alex Zucker asked welding specialist Stan David and physicist Lynn Boatner to review Laboratory research on composite materials, they concluded a multidisciplinary attack on fundamental welding problems could be fruitful.

The user facility attracting the greatest attention during the 1980s was the High Temperature Materials Laboratory. First proposed in 1977, it required a decade of efforts by Fred Young, John Cathcart, Victor Tennery, James Weir, James Stiegler, and associates to get the $20 million user facility completed. Deferred by the Reagan administration in 1981, persistent academic and industrial interest overcame the administration's initial resistance and abruptly shifted the project to the front burner. Funded in 1983, it opened in April 1987 and housed forty-nine laboratories and seventy-two offices for staff and visitors.

The High Temperature Materials Laboratory fostered exactly the sort of scientific research the Reagan administration demanded. Its collection of modern instrumentation, microscopes, furnaces, and other research equipment made possible advanced ceramics research designed to increase the competitiveness of the United States in international markets. Advanced engines operate at such high temperatures that ordinary metal alloys melt, but stronger, heat-resistant ceramic or intermetallic components could beat the heat and keep on clicking. The Laboratory's ceramic and intermetallic research promised to improve vehicle, aircraft, and rocket engines for maximum fuel efficiency. These materials also could promote development of superconducting ceramic magnets, advanced electronic components, and lightweight armor for tanks and other military applications.

When President Reagan visited the University of Tennessee in Knoxville in 1985, Director Herman Postma had an opportunity to describe Laboratory activities to him. Using its application of materials science to the development of improved artificial hip joints as an example, Postma emphasized the Laboratory's new role as a user facility seeking to expand partnerships with universities and industry. Instead of closeting its research behind a fence, the Laboratory had become a place that opened its doors to publicity and collaboration. "We have large and unique facilities in Oak Ridge, and we open them to users from throughout the country," he told the President. "We have also helped the University of Tennessee to establish centers of its own that are privately funded by industry," he went on. "Perhaps most importantly, we share accomplishments."

The Laboratory's responsiveness to a new set of national needs brought it out of the doldrums of the early 1980s into renewed prosperity. After setbacks during Reagan's first term, the Laboratory's overall operating budget rose to $392 million in 1988, slightly larger in constant dollars than it had been in 1980.

SEED MONEY FUNDING EXPANDS

Postma viewed the seed money program for unfunded exploratory studies an undiluted success. Since the program's beginnings in 1974, seed money projects had brought about four dollars in new research funding to the Laboratory for every dollar invested.

To build on this success, the Laboratory in 1984 established two new exploratory research funding opportunities: a Director's Research and Development Fund for larger projects and a Technology Transfer Fund to encourage commercially promising research. It is our "strong view," Postma asserted, "that the best judges of technical opportunities are those doing the work and their peers."

Seed money projects provided grants of up to $100,000 for one year's work, long enough for the work to produce results that could acquire attention and funding from a sponsor. The

Director's Research and Development Fund created in 1984 supported larger projects, ranging from $100,000 to $600,000, selected from proposals submitted by Laboratory divisions.

Among early projects supported by the Director's Fund was a project managed by James White to assess promising smaller, safer nuclear reactors in order to determine whether they could be commercially developed by 2010; the reactors under study included liquid metal cooled reactors, Swedish process inherent ultimately safe (PIUS) reactors, and the high-temperature, gas-cooled, prismatic and pebble-bed fueled reactors.

ROBOTICS

A third Director's Fund project of 1984 was CESAR, the Center for Engineering Systems Advanced Research. Headed by Charles Weisbin, this center focused on computer problem solving through artificial intelligence resembling human reasoning. The "reasoning" generated by machine-produced artificial intelligence was to be exercised through remotely controlled robots capable of working in such hostile environments as outer space, battlefields, areas contaminated by radiation, or coal mines.

Since the days when the Laboratory recovered plutonium from the graphite reactor and Waldo Cohn initiated radioisotopes production, remote control of operations in hostile environments had been a Laboratory specialty. Elaborate servomanipulators had been designed and built to accomplish work from behind the protection afforded by concrete or lead walls. Moreover, Mel Feldman, William Burch, and leaders of the Fuel Recycle Division had become interested in using robots to accomplish nuclear fuel reprocessing through teleoperations from a distance, or, as Feldman put it, to project human capabilities into hostile workplaces without the actual presence of humans.

With the 1984 selection of Martin Marietta Corporation as contract operator of the Laboratory, the Laboratory's robotics program found a new ally. The corporation had performed a great deal of robotics research for NASA and DOE. It had, for example, developed a robotic arm controlled from Earth for the Viking Lander on Mars, and in 1984, it was under Defense Department contract to devise "intelligent" robotic systems for automated manufacturing and assembly.

Acquiring funding from DOE, NASA, and the Army and Air Force for robotics research, the Laboratory created a consolidated Robotics and Fuel Reprocessing Division and undertook broad research aimed at developing remotely controlled robots with "common sense." In 1985, the Engineering Physics and Mathematics Division began testing HERMIES (hostile environment robotic machine intelligence experiment series), a motor-driven robot that could sense its surroundings through sonar and machine vision and respond to computer commands relayed by radio.

Investigators Manfred Mann, William Hamel, and associates improved this design with HERMIES-III, one of the worlds' most computationally powerful robots. Nearly the size of a small car, it could sense its surroundings, deal with unexpected events, and learn from experience. For Mel Feldman, this research resembled a "Buck Rogers adventure;" for children of today's generation, the Jetsons not Buck Rogers, was a more apt analogy from the world of entertainment. But for both young and old, HERMIES-III proved science's unique ability to enliven the imagination by turning the fantastic into reality.

CHERNOBYL'S FALLOUT

Oak Ridge, America, and all the world watched and worried in April 1986 as a radioactive cloud from the massive reactor failure at Chernobyl in the Soviet Union circled the globe. The Three Mile Island accident in Pennsylvania had taken place seven years before, but remained a fresh memory for many people concerned about the safety of nuclear power. The far more serious accident at Chernobyl renewed public fears and further dampened hope of reviving commercial nuclear power in the United States. The Soviet tragedy also caused a massive DOE reexamination of reactor safety throughout the nation, including detailed inspection of reactors at the agency's nuclear facilities. An industry that had been reeling from mistakes and mishaps for two decades now went into a tailspin.

DOE funding for nuclear power research at the Laboratory had been severely curtailed during the 1980s, even before the Chernobyl accident. "ORNL used to be thought of as a nuclear energy laboratory, a facility whose main mission was fission," Postma remarked in 1986. "That obviously is not the case now." The Laboratory's reactor research budget plummeted from $50 million in 1980 to $13 million in 1986, representing only three percent of the Laboratory's total budget.

A few weeks after Chernobyl, Postma appointed a committee to review safety at the aging high-flux isotope reactor. After locating and assessing the data, the committee learned the reactor's vessel had been embrittled more than predicted by twenty years of neutron bombardment. In November 1986, the Laboratory shut down the reactor for refueling and kept it idle to conduct a thorough investigation. These precautionary steps had severe impacts: it delayed neutron scattering research and neutron activation analysis; it slowed irradiation testing of Japanese fusion reactor materials; and it reduced radioisotope production for medical research. Especially critical was the loss of californium-252 production, an isotope vital for cancer research and treatment.

Concerned about reactor safety management, DOE shut down all reactors at the Laboratory in March 1987. To oversee a safe restarting of at least some of the reactors, Fred Mynatt became the associate director for nuclear technologies, and assigned responsibility for reactor operations to a new Research Reactors Division. For the first time since its inception in 1943, however, the Laboratory in 1987 had no nuclear reactors in operation.

CONCLUSION

Although no longer strictly a nuclear laboratory, the multiprogram laboratory at Oak Ridge during the 1980s savored the essence it had inherited. "The essence of a laboratory is that it experiments," Postma said, "it explores, it hurls itself against the limits of knowledge. In short, it tries. Often it fails."

Still, the change in national administrations in 1981 and the switch of contractor-operators in 1984 sparked a new phase of research within the Laboratory. The cornerstone of this new age of accomplishment was the expanding partnerships with industries and universities through its role of providing public user facilities. Between 1980 and 1988, the list of official DOE user facilities at the Laboratory had increased from three to twelve and the number of guest researchers had tripled. In 1991, the Laboratory had 3600 guest researchers at work in its user facilities; thirty percent of these guests came from industry, compared to five percent in 1980.

Technology transfer became the second highlight of the Laboratory's surprising renaissance during the Reagan and then Bush administrations. By transferring the Laboratory's scientific and technological advances speedily into the private sector, the administration and Martin Marietta Energy Systems hoped to boost the national economy and improve the competitiveness of American products in international markets. As President George Bush summed it during a 1992 visit to Oak Ridge, the multiprogram laboratory would be transformed from "the arsenal of democracy into the engine of economic growth."

As the Cold War fades into the history and international economic competitiveness becomes the hallmark of a nation's prowess, the Laboratory's ability to negotiate the challenging transformation to "an engine of economic growth" is likely to determine how well it serves the nation's interest in the 21st century and beyond.

CHAPTER IX

THE GLOBAL LABORATORY

As the Laboratory approached its fiftieth anniversary, science--always an international enterprise--assumed even broader global dimensions. Just as national boundaries were drifting away for the business world, science acquired research elements and applications that transcended national concerns. Events at the Laboratory during the 1980s and early 1990s reflected this transition.

In its quest for abundant fusion energy, the Laboratory intensified its scientific cooperation with laboratories in other nations. Its environmental research, which focused originally on nuclear power plant ecology, expanded to encompass worldwide environmental threats. Its life sciences divisions united with international efforts to map and sequence the human genome. Technology transfer, the Laboratory's keynote of the 1990s, aimed to improve the economic well being of the United States by increasing its competitiveness in world markets. In short, starting as a national scientific laboratory in 1943, the Laboratory had evolved by 1993 into a global science center.

As its global missions proliferated, the Laboratory's top management underwent transition. George Bush, who became president in 1989, had spent most of his career as a federal employee. Unlike Reagan (and even Carter), opposition to the federal government was neither the rallying cry of his campaign nor the centerpiece of his administration. Bush proposed to use government agencies, including DOE laboratories, to advance his goals.

Furnishing vigorous leadership for DOE, Bush selected Admiral James Watkins, a veteran of Rickover's nuclear navy, to head the energy agency. Watkins had attended the Oak Ridge reactor school during the 1950s and later recalled that "it was the bright minds of the academics at Oak Ridge, not the blue suit people, who inspired me to go forward in the Navy."

This national transition was paralleled by changes in the Laboratory's management. After fourteen years at the Laboratory's helm, Herman Postma transferred to the executive ranks of Martin Marietta Energy Systems in early 1988. While Associate Director Murray Rosenthal chaired a committee to select Postma's successor, Alex Zucker acted as Laboratory Director throughout 1988. A nuclear physicist, Zucker had come from Yale University to the Laboratory in 1950 and soon launched its heavy-ion accelerator program. As a naturalized citizen born in Yugoslavia, his international viewpoint inspired closer association with the global scientific community.

Although not troubled by severe budgetary constraints like those of the early 1980s, Zucker inherited several "crises" demanding Laboratory attention. Least troublesome of these crises were fears that international terrorism might extend into the United States, even to Oak Ridge. Charles Kuykendall, Laboratory Protection Division director since 1979, marshaled his division to protect Laboratory facilities against potential terrorist assaults, adding an emergency preparedness department and opening a center for high-technology security against threats to Laboratory assets. Although never subjected to international terrorism, the new safeguards proved useful, especially when the 1991 Gulf War heightened concerns about terrorism and when President Bush visited the Laboratory in 1992.

A second and longer-lived crisis of the late 1980s and 1990s involved the environmental safety and health of DOE facilities. Under new, more stringent laws and regulations, federal and state environmental officials monitored both remedial and preventive measures designed to protect human health and the environment on the Oak Ridge reservation. At the Laboratory, scores of air and groundwater monitoring devices were added and dozens of environmental safety specialists were hired to comply with the stricter standards. As part of this initiative, the Laboratory also investigated and tested new methods of waste management.

Estimates indicated that environmental restoration costs at the Laboratory could reach $1.5 billion, and that restoration costs at all DOE installations could exceed $300 billion and take more than thirty years to complete. The Laboratory's long-standing leadership in environmental restoration technology, it was hoped, could partially offset these staggering costs and provide the Laboratory with new areas of research. Officials even suggested that Oak Ridge might become an international center of excellence in waste management--the environmental restoration equivalent of California's "silicon valley." The prospects of turning a crisis into an opportunity, however, do not minimize the enormous sums of money and the army of personnel that will be applied to the cleanup.

A third crisis afflicting Zucker and the Laboratory in 1988 involved safety assurance for its nuclear reactors. DOE had closed the Laboratory's five reactors in 1987 for comprehensive safety reviews. Although the Oak Ridge research reactor had been scheduled for decommissioning, Laboratory officials thought it imperative that the high-flux isotope and tower shielding reactors be reactivated quickly to alleviate medical isotope shortages and permit the resumption of scientific experiments. Laboratory officials identified research programs that depended on the health physics and bulk shielding reactors, but funding restrictions associated with their ultimate shutdowns and prescribed environmental, safety, and health improvements precluded their further operation.

Finding quality assurance inadequate, Zucker initiated a sweeping campaign to improve it. The Laboratory's Quality Department (formerly Inspection Engineering) increased its force to twenty-eight quality assurance professionals. The Quality Assurance staff helped clear the way for the restart of Laboratory reactors, prepared quality assurance documentation in accord with new standards, and corrected deficiencies identified by internal and external quality assurance audits by DOE, Energy Systems, and other sponsors.

The principal thrust of Zucker's year of leadership aimed at boosting the Laboratory's role as an international leader in materials research. By integrating applied materials research for fossil, fission, fusion, and conservation programs, lodged chiefly in the Metals and Ceramics Division, with the basic research in the Solid State and Chemistry divisions, Zucker enhanced Laboratory capabilities for undertaking the entire spectrum of materials research down to operating the furnaces to produce new ceramics and alloys. Acquiring modern research equipment to investigate materials structures and properties became a key to developing new alloys, ceramics, and composite materials and to achieving broader understanding of surface phenomena and physical properties.

In addition to coping with the challenges facing the Laboratory in 1988, Zucker concentrated on reassuring the staff that advancing science and technology would remain the Laboratory's principal goal. Concern existed among scientists that high priorities assigned to environmental, safety, and health compliance, and the prime consideration given to compliance in setting award fees for the contractor-operator, would make Laboratory research more conservative and risk-adverse. To alleviate this and related concerns, Zucker initiated active planning and program development efforts for science and technology and emphasized the Laboratory's user facilities and technology transfer opportunities.

By the time Alvin Trivelpiece became the new Laboratory

Director in early 1989, Zucker could report progress in resolving many of these challenges. The Laboratory had improved its emergency response system, consolidated its materials research efforts, promoted innovative waste management technologies, and stood ready to resume reactor operations. There would be no quick fix, however, to the last two crises. In fact, waste management and reactor operations would help define the Laboratory's agenda in the 1990s--and, undoubtedly, will shape its agenda in the years beyond.

An electrical engineer and physicist from California, Trivelpiece had visited the Laboratory when conducting research on fusion plasma physics. He had broad government experience as well, serving with the AEC before it closed in 1973 and later heading DOE's Office of Energy Research from 1981 to 1987, a position that brought him to the Laboratory several times. He was serving as executive director for the American Association for the Advancement of Science in Washington when he agreed to move south to head the Laboratory. As the first Director in forty years appointed from outside Oak Ridge, his selection further enhanced the Laboratory's global approach to science.

TRIVELPIECE REORGANIZES

In his first address as Director in 1989, Trivelpiece outlined the themes of his administration. "As a national laboratory, we need to be able to respond both to inflicted change and to the changes we may cause to occur," he declared. "We need to be a competitor," he added, "we need to be serious about competing, and to be taken seriously as a competitor in the world's research and development efforts."

Trivelpiece agreed with Admiral Watkins that the erosion of American leadership in international science and technology had sapped the underpinnings of the national economy. This leadership had to be regained through improved science education and faster transfer of technologies from the lab bench to the world of commerce.

Preparing to meet these international challenges, Trivelpiece reorganized Laboratory management. Zucker continued as associate director for nuclear technologies, a post he held until moving to the Energy Systems executive staff in 1992. Trivelpiece, however, made Murray Rosenthal his deputy director for administration and gave him primary responsibility for health, safety, and the environment. William Fulkerson succeeded Rosenthal as associate director for advanced energy systems.

As part of the reorganization, Trivelpiece strengthened the responsibilities of the Office of Planning and Management (formerly the Office of Program and Planning Analysis) with Beverly Wilkes and Truman Anderson serving successively as the director. He supported the formation of a Center for Global Environmental Studies, an Office of Guest and User Interactions, and an Oak Ridge Detector Center (the latter designed to respond to research opportunities created by the enormous particle accelerator--the Superconducting Super Collider--scheduled to be built in Texas).

In addition, Trivelpiece created an Office of Laboratory Computing, managed by Carl Ed Oliver, to implement strategic plans for grand challenges in computational science. This office aimed to provide Laboratory scientists with access to the most advanced high-performance supercomputers. In partnership with universities and other laboratories, these supercomputers would help Oak Ridge confront key scientific challenges of the late 20th century--the unknown frontiers in global climate research, human genome sequencing, high-energy heavy-ion physics, and materials sciences.

Trivelpiece also enlisted the Laboratory in a campaign spearheaded by Secretary Watkins and President Bush to foster science and mathematics education. In February 1990, he appointed Chester Richmond director of the Laboratory's science education programs, an announcement that coincided with President Bush's visit to Knoxville to boost public support for science education. Under this initiative, the Laboratory expanded its educational programs fostering elementary and secondary science education, hosting high school honors workshops and teacher training seminars. The science education program further strengthened Laboratory cooperation with minority educational institutions in an effort to attract new students into the world of science. More than 16,000 precollege students visited the Laboratory in 1991, many participating in weekend academies for computing and mathematics.

When Richmond moved to the science education programs in 1990, David Reichle succeeded him as associate director for biomedical and environmental research, later expanded to include the Energy Division and renamed the Environmental, Life, and Social Sciences Directorate. By 1992, these "soft" sciences led the Laboratory advance into research on global environmental change, economic competitiveness, and human health. They accounted for about a quarter of the Laboratory's total staff and budget.

REACTOR MANAGEMENT

Restarting its reactors was at the forefront of the Laboratory's agenda at the time of the Bush-Watkins-Trivelpiece transition. After the completion of twenty safety investigations, DOE's Oak Ridge Operations manager, Joe LaGrone, recommended restarting the high-flux isotope reactor in late 1988. And in March 1989, Admiral Watkins surprised a Senate committee by announcing his decision to resume reactor operations at Oak Ridge.

Managed by Robert Montross and later by Jackson Richard, the high-flux isotope reactor was restarted in April 1989 and, after operational difficulties, ran at eighty-five percent of its original power. The Laboratory restarted its tower shielding reactor in December 1989, allowing shielding studies for breeder reactors funded by the United States and Japan to proceed. The Laboratory mothballed its bulk shielding, health physics, and Oak Ridge Research reactors, however, and initiated steps to decommission them, although Jackson Richard believed the valuable health physics reactor deserved retention as a national asset, either in Oak Ridge or elsewhere.

GLOBAL ENVIRONMENTAL CHALLENGES

Laboratory efforts to quantify and resolve threats to the global environment began as early as 1968, when Jerry Olson of Environmental Sciences Division initiated studies of carbon dioxide in the world's atmosphere. In 1976, Alex Zucker expressed concern about global warming--that is, the potential for temperatures to rise largely because of increased carbon dioxide concentrations in the Earth's atmosphere--and assembled a team composed of Olson, Ralph Rotty, Charles Baes, and Hal Goeller, to study the problem and recommend appropriate Laboratory actions. Observing that concentrations of carbon dioxide in the air had increased steadily since the beginning of the industrial revolution, the team identified the sources and sinks of carbon dioxide, pinpointing the crucial role of absorption in the oceans and the great uncertainties connected with the problem.

With DOE support, the Laboratory began analyses of emerging global environmental concerns related to energy use. The burning of fossil fuels and of forests were cited as prime causes of the steady buildup of carbon dioxide in the atmosphere. Fossil fuel burning also was linked to the formation of acids in the atmosphere, which rained down on forests hundreds of miles from the sources.

During the late 1970s, Hank Shugart and David Reichle proposed to DOE a study of the global carbon cycle and its relationship to fossil fuel burning. This helped encourage DOE to undertake a major global carbon dioxide program. With Reichle, John Trabalka, and Michael Farrell of Environmental Sciences Division providing leadership, the Laboratory adopted an interdisciplinary research strategy to identify the sources, migration, distribution, effects, and consequences of global warming and acidic rain deposition. This, in turn, sparked vigorous experimentation at the Laboratory on global biogeochemistry.

Laboratory scientists used computer modeling to estimate how additional accumulations of carbon dioxide in the atmosphere might induce future global climate changes. Some models predicted intense global warming, with potentially calamitous effects on trees and crops. In the field, Laboratory scientists examined tree rings and fossil pollen grains taken from lake sediments to detect past climatic conditions and trends. For example, from radiocarbon-dated sediment taken out of Tennessee ponds, Hazel Delcourt and Allen Solomon analyzed fossil pollen grains to reconstruct changes in regional vegetation over 16,000 years. With this paleoecological evidence, they estimated the future effects of carbon dioxide concentrations on vegetation and the climate.

The greenhouse effect and acid rain were truly global challenges, and quantifying their results and devising potential solutions required an understanding of complex physical, chemical, and biological processes on a global scale. The Laboratory's approach, therefore, expanded to include global monitoring, measurement, and modeling using the largest, fastest computers available. The Laboratory took the lead in formulating global carbon simulation models and became responsible for managing the DOE research effort, subcontracting studies to universities and other laboratories and establishing the national carbon dioxide information center to compile and disseminate pertinent data.

To investigate acid rain and its effects, the Environmental Sciences Division installed rainmaker simulator chambers in a greenhouse and programmed them to control raindrop size, intensity, and chemical composition; for comparison purposes, they built an identical system using unpolluted water. These experiments examined the consequences of prolonged ecosystem exposure to rain polluted by oxides, ozone, and other materials. The accumulated data helped set regulatory standards for environmental protection.

In the late 1980s, the Electric Power Research Institute and other agencies funded Laboratory studies of the effects of acids on streams in the Appalachian, Great Smoky, and Adirondack mountains. Ernest Bondietti managed this project, which sought the cooperation of a dozen universities in the eastern forest region. Early results indicated that acids in mountain streams had natural geologic in addition to manmade atmospheric sources.

At the Laboratory's Walker Branch Watershed, Dale Johnson and Daniel Richter conducted forest-nutrient cycling research on the soil-leaching effects of acid deposition, and in 1992 the Laboratory announced the Watershed would be the site of the first large-scale field studies of climate change effects.

This and other research supported a steady growth in the Laboratory's environmental sciences program. With about 200 full-time employees and more visiting university faculty and students than other divisions, the Environmental Sciences Division built an international reputation.

In July 1989, Trivelpiece announced the formation of a Center for Global Environmental Studies to be managed by Robert Van Hook and Michael Farrell from Environmental Sciences Division. "Its goal," Trivelpiece said, "would be to achieve better understanding of global air, land, and water environments and more accurately predict the consequences of human activities on the world's ecological balance." The Center would focus its attention on the causes and effects of such global challenges as greenhouse warming, ozone depletion, acid rain, and deforestation.

By the early 1990s, the Laboratory had conducted major studies of ozone depletion, or what the media commonly called the "ozone hole." In cooperation with industry, the Laboratory joined in the search for acceptable substitutes for chloroflourocarbons (CFCs) in refrigerants, insulation, and commercial solvents. Studies at the Laboratory's Roof Research Center in the Energy Division, for example, focused on testing foam-board insulation made with CFC substitutes.

HOT AND COLD FUSION

Fusion energy researchers were shocked when two chemists from the University of Utah announced in a March 1989 press conference that they had achieved cold fusion. By passing electricity through chunks of metal immersed in electrochemical jars of heavy water, they said they had produced heat and the neutron byproducts of a fusion reaction. If true, the discovery offered an inexpensive alternative to "hot" fusion as an unlimited energy source.

Trivelpiece learned of this astounding accomplishment from the front pages of his weekend newspaper. "I used the only scientific tool available to me that weekend--a push-button telephone," he later remembered, "and called everyone I knew who might be able to help me and I tried to find out as much as I could."

His discussions with Laboratory colleagues revealed they thought the chances were slim for cold fusion but that the Laboratory should investigate it fully. By direction of Secretary

Watkins, the Laboratory accelerated studies of cold fusion the following week. Teams in the Physics, Metals and Ceramics, Chemical Technology, and Engineering Physics and Mathematics divisions energized a dozen electrochemical cells to test the cold fusion claims, using more sensitive neutron detection devices than available to the purported discoverers of this energy source. Michael Saltmarsh of Fusion Energy Division chaired a Laboratory committee compiling information on these experiments.

Within a month, Saltmarsh testified before a House science committee that the Laboratory had been unable to detect excess heat or radiation in its cold fusion experiments. This and reports from other laboratories discredited the discovery of cold fusion, although limited experimentation continued in hope that some yet-to-be explained phenomenon was occurring in the electrochemical cells. As late as 1992, a Japanese scientist reported excess heat emanating from his cold fusion experiment, although he acknowledged that it did not emit the neutrons characteristic of a fusion reaction.

Achieving magnetically confined hot plasma therefore remained a major technological challenge at the Laboratory and throughout the world of science. This pursuit assumed cooperative global proportions during the 1980s, especially at the Laboratory's large coil testing stand named the International Fusion Superconducting Magnet Test Facility.

All major industrial nations conducted research on fusion power during the 1980s and on the superconducting magnets needed for successful fusion energy production. In cooperation with the International Atomic Energy Agency, DOE approved construction of a large magnetic coil facility at Oak Ridge to test huge superconducting magnets--three designed and fabricated in the United States by General Electric, General Dynamics, and Westinghouse and three overseas in Japan, Germany, and Switzerland. All used specifications written at the Laboratory so that the magnets would fit into the large coil test facility.

The Laboratory installed the six magnets, weighing forty-five tons each, in the toroidal (doughnut-shaped) large coil facility. When its stainless steel vacuum chamber lid was lowered into place atop the magnets and the proper vacuum was achieved, its refrigeration system (which used helium) chilled the magnets to almost absolute zero. Paul Haubenreich managed comparative testing of the magnets during 1986 and 1987, checking their ability to withstand thermal, mechanical, and electrical stresses and determining whether superconducting coils were practical for confining the plasma of fusion reactors.

The large coil stand operated reliably during twenty-two months of testing and the magnets performed well, setting records as the largest superconducting magnetic coils in size, weight, and energy ever operated. It also marked the first time that four nations--the United States, Germany, Japan, and Switzerland--had submitted unique versions of similar equipment to collaborative testing for evaluation of their performance, reliability, and costs.

The 1988 report on the experiment found that the magnetic coils in operation had exceeded their design parameters, indicating that much larger magnets could be built using similar design procedures. The report observed that the successful international cooperation marking the large coil tests boded well for other cooperative global ventures in fusion research.

These conclusions proved useful in the design of the International Thermonuclear Energy Reactor (ITER) planned as a joint effort of the United States, Russia, Japan, and the European community. This thermonuclear energy reactor was being planned as the first fusion reactor in which studies of ignited and burning plasmas could be conducted.

Within the political and scientific communities of the Unites States, some observers recoiled at the costs of long-term fusion research, fearing that federal research funds would not be available for the long haul. After all, scientists projected that successful fusion energy generation would not occur until the mid twenty-first century. "Let us not grow weary while doing good," warned William Happer, chief of DOE's Office of Energy Research. Quoting a letter from the Apostle Paul to the Galatians, Happer continued, "for in due season we shall reap if we do not lose heart."

The Laboratory expected to play a significant role in the International Thermonuclear Energy Reactor program, and Paul Haubenreich, manager of the large coil tests, went to Europe for several years to work in that program. After completing the large coil tests, Martin Lubell and the Laboratory's superconductivity team turned to potential commercial investigations of motors using superconducting materials. Their superconducting motor was in operation by 1992.

STELLAR PERFORMANCE

Other Laboratory advances in fusion energy research during the late 1980s and early 1990s included improved plasma fueling and heating devices and the construction and testing of an advanced toroidal facility, a stellarator fusion reactor shaped more like a cruller than the tokamak doughnut.

Pioneered by Stanley Milora and Chris Foster at the Laboratory, fueling fusion plasmas by freezing deuterium into pellets and firing them into reactors became the standard fueling method worldwide, and the Laboratory became DOE's lead agency for plasma fueling technology. For the ever-larger fusion reactors, the Laboratory fabricated bigger pellets, discharging them into plasmas using an electron beam accelerator to vaporize their back end and provide a rocket-like forward thrust. The Laboratory also completed a radio-frequency facility in 1985 to test the heating of fusion plasmas, and it joined with Japan's energy institute to conduct collaborative testing at Laboratory reactors of the structural alloys for fusion devices.

The Laboratory also designed and built an advanced toroidal facility to supplant its impurities experiment tokamak of the 1970s. Called a torsatron or stellarator, the advanced toroidal facility had a helical field for plasma confinement provided entirely by external coils, instead of relying on currents within the plasma like the tokamaks did. Aiming to create more stable plasmas, it afforded a steady, rather than a pulsed, operation, which utility systems preferred for electric power generation.

After four years of construction, the Laboratory in 1988 completed its precision-crafted stellarator, with more than twice the plasma volume of previous stellarators. Its principal purpose was to determine the pressure and stability limits for improved toroidal designs. Testing soon identified a second stability phase in the plasma, which Zucker termed a major advance in fundamental plasma physics. The Laboratory sought funding during 1992 for a restart and continued testing of this stellarator, which was the only fusion machine in the United States capable of operating in a steady state.

PARTICLE ACCELERATORS

Global scientific cooperation is a two-way international highway. In the 1980s, the Laboratory dispatched two of its large calorimeters and ten of its scientists to the European Laboratory for Particle Physics (CERN) in Switzerland to participate in experiments aimed at observing individual quarks outside nuclei. The experiment fired oxygen nuclei into target nuclei of carbon, copper, silver, and gold at ultra-high energies, dramatically demonstrating the conversion of energy into matter. The Laboratory calorimeter team saw particles bombarding the gold nuclei multiply into many more particles.

As a former physics professor, Trivelpiece thought the creation of mass from energy fascinating, and he penned a vivid description of this feat:

> Think of a couple of reckless mechanics who decide to try to figure out how an internal combustion engine works by driving two automobiles together at a hundred miles an hour and then examining the scattered parts. Even if they find the normally expected parts, such as pistons and a carburetor, they would still have a hard time figuring out how the engine works. But imagine their dilemma if, instead of the expected parts, they find two Mack trucks, a bulldozer, and a bunch of tricycles all nicely assembled and working.

Trivelpiece was credited with persuading the Reagan administration to explore these mysteries through construction of a Superconducting Super Collider, a fifty-three-mile long oval track to be built underground in Texas where two opposing beams of protons would circle and collide. Seeking to determine whether quarks are the fundamental units of matter or if they can be further subdivided, this huge science racetrack will be the world's most powerful accelerator, if Congress agrees to fund the project to its completion.

Laboratory participation in the supercollider project involves developing detectors to determine the results of the collisions. The Laboratory formed an Oak Ridge Detector Center, directed by Tony Gabriel, in 1989. The center hoped to be at the forefront of developing central-system particle detectors for the supercollider that could track and measure the directions and initial energies of secondary particles produced by the collisions. Recognizing the value of these devices to global science, the Laboratory consulted physicists from many nations for the detector designs, which were still under development in 1992.

GLOBAL HUMAN GENOME INITIATIVE

Inspired by an Office of Technology Assessment report on detecting inherited mutations in human beings, the DOE Office of Health and Environmental Research in 1987 launched an international campaign to map and sequence the three billion chemical bases in human DNA. Charles Cantor and colleagues at Columbia University had mapped and sequenced the *E. coli bacteria*, and Larry Hood and fellow researchers at the California Institute of Technology had developed automated sequencing equipment. Among the practical benefits of sequencing the human genome could be new diagnostic tests and therapies for genetic diseases.

Through participation in long-term international studies of the survivors of the Hiroshima and Nagasaki bombs, Laboratory researchers had obtained experience in human gene studies, and during the 1970s, the Biology Division had devised gene mapping techniques for the study of mutagens and carcinogens.

Searching for genes that might inhibit cancer, they had identified individual genes and assigned them to specific chromosomes. Laboratory capabilities were further enhanced by development during the 1980s of improved scanning tunneling microscopes that could obtain images of DNA strands. These microscopes could help determine the locations of genes on cell chromosomes (mapping) and the arrangement of DNA bases in the genes (sequencing) of the human genome. Sponsored by DOE and NIH, the human genome studies, an immense computer-intensive investigation, became global in scope, with various nations sharing the research and its costs.

Yet, the Laboratory in 1990 had no externally funded human genome projects when David Galas, newly appointed director of DOE health and environmental research programs, visited Oak Ridge. Shrewd selection of research projects for seed money funding and advance negotiation by Bruce Jacobson set the stage for convincing Galas that the Laboratory's facilities should be involved in the genome challenge. Six Laboratory divisions were subsequently participating in genome research, focusing on learning the order of chemical bases that make up DNA and locating specific genes to determine their functions.

Using mass spectrometry, gel electrophoresis, radiolabeling, laser ionization, and other research techniques, the Laboratory obtained information on the genome. It also provided a forum for international exchange of genome information in its Human Genome Management Information System, located in the

Health and Safety Research Division.

When visiting Oak Ridge in 1990, David Galas, chief of DOE's Human Genome Program, observed that the Laboratory was a gold mine of knowledge about mouse genetics that might be useful to human genome researchers, and he sought collaboration between Laboratory mouse experts and the DOE and NIH genome centers. One outgrowth was a program funded by the National Institute of Child Health and Human Development for researchers in the Biology Division led by Richard Woychik and Gene Rynchik, who used transgenic mice to help ascertain the locations and molecular structure of human genes, thereby advancing understanding of human genetic disorders.

The Laboratory, DOE, NIH and, more generally, the international life sciences community hoped to obtain information on genes that would help them determine, for example, which genes are responsible for muscular dystrophy, cystic fibrosis, and Huntington's disease. With this information, scientists might be able to devise methods for repairing these genetic disorders. Program advocates implied it might contribute eventually to ameliorating mental health problems by identifying the multigenic causes of manic depression, schizophrenia, and Alzheimer's disease. The most avid proponents asserted that successful completion of this global project could place human intelligence in control of its genetic destiny, although critics questioned the wisdom and ethics of this goal.

ENVIRONMENT, SAFETY, AND HEALTH

In June 1989, Admiral Watkins outlined a "new culture of accountability" for DOE to regain its credibility in environmental restoration compliance. He approved providing state agencies access to DOE installations to monitor DOE compliance with environmental standards and regulations. DOE also emphasized environment, safety, and health compliance in awarding fees to contractor operators of its facilities, mandated full compliance with Occupational Safety and Health Administration standards, and formed "tiger teams" to assess field agency compliance and corrective measures.

These measures were a belated response to the 1984 amendments to the Resource Conservation and Recovery Act stipulating that facilities handling hazardous wastes must reduce the generation of such wastes and remediate situations where wastes had escaped into the environment. It soon became apparent that remediating hazardous wastes would be time consuming and costly--that there would be no cheap, quick fix. John Gibbons, director of the Office of Technology Assessment, who previously had worked at both the Laboratory and the University of Tennessee Energy, Environment, and Resources Center, declared, "Decades will be required for cleanup of certain sites while others will never be returned to pristine conditions."

As an incentive to reduce wastes, the Laboratory adopted a charge-back policy, billing waste disposal costs to the division which generated the waste. Thereafter, Laboratory research and development proposals incorporated waste disposal into their estimated project costs, encouraging researchers to avoid using toxic substances in their experiments. "It's a new mentality, a cultural change," Thomas Row insisted.

Thomas Row, who in 1991 became director of a consolidated Environmental, Safety, and Health Compliance Division, described major changes in Laboratory waste disposal methods reflecting the new corporate culture. Historically, the Laboratory had placed solid low-level wastes, such as contaminated glass and rags, into unlined trenches; now it packaged such waste in steel cans inside concrete vaults eventually entombed in earth berms with monitored drainage systems. Low-level liquid wastes, once handled using underground hydrofracture, were now concentrated and compacted to reduce the volume, then solidified and stored above ground. The Laboratory's spent reactor fuel went to the Idaho or Savannah River complexes, which had storage facilities for reactor fuel requiring reprocessing. The Laboratory's transuranic wastes were stored on-site in specially designed bunkers for eventual disposal at a DOE centralized facility, perhaps the Waste Isolation Pilot Plant in New Mexico. One measure of the Laboratory's commitment to environment, safety, and health programs was its increase of program personnel from 240 in 1988 to 390 in 1990.

In 1988, about fifteen percent of the Laboratory budget was devoted to waste management and remedial actions--and this was only the beginning. To reduce waste management and remediation program costs, Admiral Watkins challenged the national laboratories to find ways to treat the contamination without moving it. One Laboratory response involved *in situ* vitrification, which entailed passing electric currents underground through hazardous wastes, heating them to high temperatures and thereby converting them into glass-like solids impervious to groundwater. Developed at the Pacific Northwest Laboratory, *in situ* vitrification was tested by Brian Spalding and colleagues at Oak Ridge National Laboratory to isolate strontium and cesium. Although still an expensive technique, *in situ* vitrification could be used to treat the pits and trenches that served as waste repositories during the Laboratory's early years.

Another innovation was bioremediation, which used microorganisms to break down hazardous chemicals in the ground. Laboratory teams used methane-consuming microorganisms in the soil to destroy subsurface chlorinated metal-cleaning solvents. Additional research was underway in 1992 to identify or modify microorganisms to consume other types of toxic wastes.

TIGERS ON THE PROWL

To assure full compliance with environmental and safety programs, Admiral Watkins dispatched "tiger teams" to DOE field agencies for thorough operational and management inspections.

With a tiger team ready to pounce on Oak Ridge in 1991, the Laboratory instituted a massive cleanup in advance of the inspection. Its Plant and Equipment Division, for example, installed more than 1500 new safety guards on 574 machines. Within a month after the lengthy inspection, the Laboratory's response team had corrected 366 deficiencies identified by the tigers.

Complimenting William Fulkerson, Jerry Swanks, Frank Kornegay, Bill Morgan, Tony Wright, and David Reichle on their leadership of the Laboratory's lion-hearted response, Trivelpiece declared the tiger team inspection largely a success, although he also pointed out that the Laboratory had not received a complete clean bill of health. "We did not come through unscathed," he admitted. "There are a lot of problems: legacies from past practices, deficiencies in current programs, and management deficiencies and improving acceptance for environmental safety and health." Yet, he thought the tiger team inspection had served as a catalyst for progress.

DEFENSE CHALLENGES

Visiting the Laboratory in 1992, President Bush referred to it as an "arsenal of democracy." Although a scientific rather than a weapons laboratory, the Laboratory had supported national defense in several programs. In addition to assisting the Strategic Defense Initiative, the Laboratory undertook research during the 1980s for the Defense Department that included investigations of defense materials, computer vision, battlefield logistics, robotics, instruments and controls, and electromagnetic interference.

Also for the Defense Department, the Laboratory's radioisotopes group directed by Neil Case developed isotope-powered lights using krypton and tritium to excite phosphor pellets, causing them to glow in the dark. These "plugless" lights provided landing and distance markers for military and civilian pilots in remote areas. In another case, Cabell Finch and Lynn Boatner of Solid State Division developed doped crystals for room-temperature promethium lasers. These crystals were suited for satellite-to-submarine underwater communications because their light could be transmitted through water.

Led by the Energy Division's Samuel Carnes, in 1987, a Laboratory team completed the final programmatic environmental impact statement for disposal of the Army's stockpiled chemical weapons. The team identified on-site incineration as the environmentally preferred method of weapons disposal management.

When terrorists bombed aircraft during the 1980s, a team in the Analytical Chemistry Division devised an explosives sniffer using mass spectrometry to test the air for suspect chemicals, thereby determining in seconds whether explosives were present. This interested airport security firms, and Energy Systems licensed the "sniffer" to a private company for commercial use.

In addition, the Laboratory in 1992 tested an "ion trap mass spectrometer." Installed in a van, this complicated equipment could serve as the basis of a mobile laboratory for rapid detection of contaminants at environmental cleanup sites. Providing test results much faster than conventional methods, the device was expected to produce substantial savings for the cleanup programs of both DOE and the Army Toxic and Hazardous Materials Agency.

Computer models developed by the Laboratory's Center for Transportation Analysis in the Energy Division saw useful application during the 1991 Gulf War. The U.S. Transportation Command used the software to schedule deployment of equipment to the Middle East for Operations Desert Shield and Desert Storm in the largest airlift operations in history.

Successful national defense ultimately rests on economic prosperity, and during the 1990s the Laboratory increasingly focused its resources and staff on environmental and economic, not military, matters. The key words for this operation were "technology transfer" and "national competitiveness."

TECHNOLOGY TRANSFER CHALLENGE

Laboratory efforts to transfer its technological advances to industry began in 1962, when Weinberg established an Office of Industrial Cooperation to reduce the time required for the civilian economy to adopt scientific advances. Carol Oen and Don

Jared headed Laboratory technology utilization offices during the 1970s and found partial success through spinoff industries often launched by former Laboratory personnel. The Laboratory also helped lure Boeing Engineering, Science Applications, System Development, TRW, Exxon, Bechtel, and other corporations to Oak Ridge, simply by increasing public awareness of the Laboratory's technical capabilities.

Legal barriers involving patents and nonexclusive licensing, however, hampered quick technological transfer. Corporate executives were reluctant to invest in technology without the marketplace advantage of holding the exclusive rights to a particular technology.

Recognizing the latent economic power in the national laboratories, Congress passed legislation during the 1980s to encourage technology transfer. The Laboratory's new contractor operator, Martin Marietta Energy Systems, vigorously promoted this initiative. In 1985, for example, Energy Systems signed an exclusive license with Cummins Engine Company to use in diesel engines the intermetallics developed by C.T. Liu and his colleagues. Energy Systems offered financial incentives to Laboratory personnel who applied for patents as well. Laboratory inventors received the first royalties for their innovations in 1987.

Direct cooperation with industry at the Roof Research Center, High Temperature Materials Laboratory, and elsewhere quickened the pace of transferring ceramics, semiconductors, electronics, computer software, insulation, and other commercially promising technology. As a result, the Laboratory led DOE in technology transfer, and its program became a model for other laboratories.

Industry expressed great interest in the Laboratory's development of ceramic gelcasting and material reinforcement with whiskers made from rice husks. By 1989, eleven companies had obtained licenses to use durable whisker-toughened ceramic composites in metal cutting tools, and a license for using gelcasting to shape ceramics, invented at the Laboratory, went to Coors Ceramics Corporation. Coors built a plant in Oak Ridge to pursue this and related technologies.

Trane Company, a worldwide manufacturer of air conditioning and refrigeration systems, acquired a license for gas-powered absorption chillers invented at the Laboratory. These chillers were more economical than electric chillers and could reduce summer demands for electricity by shifting some of the air-conditioning load to natural gas.

Energy Systems issued its first royalty-bearing license in nuclear medicine to DuPont in 1989. Prem Srivastava and associates in the Health and Safety Research Division had synthesized a chemical compound useful for cancer detection that DuPont expected to market to medical research institutions.

OPEN FOR BUSINESS

A 1989 Technology Transfer Act amended the Atomic Energy Act to make technology transfer a principal mission of DOE and its laboratories. The act allowed contractor-operated laboratories such as Oak Ridge to work directly with industries, universities, and state governments, jointly sponsoring research and sharing information through Cooperative Research and Development Agreements (CRADAs). "The labs are now open for business," proclaimed William Carpenter, Energy Systems' chief of technology transfer.

In 1990, the Laboratory entered its first CRADA, joining an international chemical consortium to study chemicals that could serve as alternatives to chlorofluorocarbons (CFCs). More CRADAs followed. During his February 1992 visit to the Laboratory, President Bush highlighted this technology transfer program at the signing of a CRADA with Coors Ceramics to develop precision machining of ceramics.

Touring the High Temperature Materials Laboratory and addressing a crowd in front of the building, President Bush praised the $3.6 million CRADA with Coors as an intelligent way to take technology directly to markets and create new jobs. "The High Temperature Materials Laboratory is a world-class facility," he declared, "and in the race with other nations in making precision parts, America will get there first." After Trivelpiece and Coors signed the CRADA, Coors presented the president with a ceramic golf putter as a light-hearted sample of the products that could flow from the materials research.

Speaking in Knoxville later that day, the president promised significant increases in funding for science education and the National Science Foundation. Thus, the president's brief visit to Oak Ridge and Knoxville framed, in national terms, two of the Laboratory's most important initiatives of the 1990s--technology transfer and science education.

FUTURE CHALLENGES

When listing the future priorities of the "broadest based and most multidisciplinary of the DOE national laboratories," Alvin Trivelpiece highlighted his hope that the Laboratory will become the center for excellence in research reactors. Its high-flux isotope and tower shielding reactors were back in service, although the latter was funded primarily by a Japanese-sponsored program for shielding studies.

In 1992, The Laboratory pressed for funding to design a major new reactor to replace its aging high-flux isotope reactor. Named the advanced neutron source, studies of this proposed reactor had begun in 1984 as a Director's Fund project. Leadership in neutron scattering and radiation research and the production of heavy elements for research and isotope production had passed to Europe during the 1980s when a reactor with a neutron flux greater than that of the Laboratory's reactors was completed at Grenoble, France. The Laboratory urged that building the advanced neutron source would regain world leadership for the

United States by providing the most intense continuous neutron beams in the world.

Initiated by Ralph Moon and managed by David Bartine and Wallace Gambill with Colin West as group leader, the conceptual design for the advanced neutron source enlisted the aid of prominent scientists throughout the world. Surrounding the reactor would be a national research center, with adjoining structures housing neutron scattering and physics experiments and offices for scientists from both the Laboratory and elsewhere.

The initial reactor design called for heavy water to cool and reflect neutrons back into the core. (The high-flux isotope reactor used ordinary water as coolant and beryllium as a neutron reflector.) Studies by the Laboratory and the Idaho National Engineering Laboratory led to the selection of a split core configuration and of aluminum cladding for a uranium silicide fuel. This would create a 350-megawatt powerhouse, compared with the original 100-megawatt rating of the high-flux isotope reactor.

Noting that the Laboratory had built and operated fourteen nuclear reactors (counting the 1955 Geneva conference reactor and the pool critical assembly), Murray Rosenthal observed that this advanced neutron source would become the Laboratory's fifteenth reactor and the first one built since 1966, when the high-flux isotope reactor began operating. Colin West estimated its 350-megawatts would provide a neutron flux quadruple that of the high-flux isotope reactor and perhaps a million times greater than the flux available to Wollan and Shull at the 1943 graphite reactor. John Hayter, scientific director for conceptual design, said the new reactor's plans included thirty-two beam lines with instruments at their ends, and new features such as neutron mirrors for beam delivery and a cold source (a tank of liquid deuterium) to slow the neutrons as they passed through the "guide hall" to experimental laboratories.

The conceptual design involved personnel from national laboratories, industries, and universities, plus researchers from Germany, Japan, and Australia. By 1992, more than a thousand non-Laboratory scientists had signed on to conduct research at the advanced neutron source when it became operational. With the aging high-flux isotope reactor operating at reduced power, early completion of the advanced neutron source seemed vital. "When the HFIR reaches the end of its useful life, we will need a new reactor to enable U.S. scientists to conduct neutron-scattering studies to make progress in certain key fields," Trivelpiece asserted. "I think," he added, "we need to make a full court press, and I regard this project as the highest priority technical facility pursued by the Laboratory."

Other ongoing reactor programs at the Laboratory included the modular high-temperature gas cooled reactor research program, promising safety and investment protection features unavailable in other efficient reactor concepts. The Laboratory also provided research and design review support for the liquid metal fast reactor with potential for greatly extending the nuclear fuel supply, and it provided review services and research through DOE's work with improved light water reactors of modular size and improved safety characteristics. Laboratory support for safety studies and research for the Nuclear Regulatory Commission was expected to continue, with the heavy section steel program as a flagship project.

Established in 1943 as a nuclear reactor, chemical separations, and scientific laboratory, the Laboratory continued to build upon these traditional strengths in 1993. Nevertheless, broadening investigations of other energy forms, of environmental safety and health, and of scientific advances that sought to improve national economic competitiveness absorbed larger and larger portions of the Laboratory's budget and energies as it approached the end of the 20th century. The Laboratory's future seemed to lie not so much in its ability to do research in specific nuclear projects as in its deeply rooted skills to undertake large-scale, complicated projects that addressed broad national needs and concerns.

EPILOGUE

Nearing retirement in 1992 after fifty years of service to the Manhattan Project and the Laboratory, senior staff advisor Donald Trauger reflected on the lessons of a half century. The Laboratory and science at large, he urged, should expand their strategic planning to longer time spans. "Recent experiences in changes of national administration have limited effective implementation of some programs to four years or even two years, and industry is shortening its planning to as little as two years because of high capital costs and demands for early returns on investments. Perhaps," he suggested, "the national laboratories...can effectively consider the time spans that are really desirable. Even 100 years is not as distant as we might have thought."

Laboratory management, as always, devoted considerable attention to planning the institution's future research and considering the equipment and facilities needed to support world class science. The Department of Energy, in fact, has required the Laboratory to prepare institutional plans looking five years into the future, and in 1990 Director Trivelpiece formed a planning group to analyze the Laboratory's long-term corporate strategy.

In addition to assigning the highest priority to the Laboratory's proposed advanced neutron source and other nuclear reactor studies, Trivelpiece emphasized the global importance of the work of Thomas Wilbanks, Milton Russell, and Energy Division teams, who by 1992 had assisted twenty-one nations with the development of their energy and environmental technology policies. Pointing out that events in these nations had ramifications for the U.S. and global environment, Trivelpiece urged Congress to support Laboratory efforts to assist other nations in meeting their energy needs while reducing the strains on the environment and world oil markets.

To improve science education, Trivelpiece advocated greater cooperation with Oak Ridge Associated Universities, Pellissippi State, the University of Tennessee, Tennessee state government, and regional school systems. He was particularly interested in designing classrooms for the 21st century, using reasonably priced electronic teaching aids and student work stations.

For the 1990s and beyond, Trivelpiece and the strategic planning group expected Laboratory directions to be dominated by four major themes: education, energy, environment, and economic competitiveness. These efforts were to be supported by three new major user facilities the Laboratory hoped to complete within a decade: the advanced neutron source and its adjoining research facilities (described in the previous chapter), and two new user centers--a material science center on the east end and an environmental and life sciences center on the west end.

Demonstrating the increasing importance of materials science to the Laboratory's efforts to improve national economic competitiveness was the proposed Materials Science and Engineering Complex, which the Laboratory hoped to construct near the Holifield Heavy Ion Research tower. Consolidating existing programs in new facilities to enhance scientific interaction, the complex would include centers for solid state research and processing, advanced microstructural analysis, advanced materials research, and composite materials investigations.

Explosive growth in the materials science and its major role in the Laboratory's technology transfer programs since 1980 had severely overcrowded existing laboratories, and building the new complex to house the programs was considered more economical than upgrading older structures to meet modern environmental and safety standards. Presidential initiatives presaged substantial funding increases for materials sciences research during the late 1990s, and the proposed new complex at the Laboratory aimed to enhance the on-site involvement of university and industrial researchers in cooperative ceramics, composites, superconductors, and high temperature metals and alloys projects. This proposed complex, therefore, enjoyed strong support from universities and industries in the Southeast.

At the western gate, near the existing Environmental Sciences and Aquatic Ecology laboratories, the Laboratory proposed to develop an Environmental, Life, and Social Sciences Complex. The complex would include centers for biological sciences, Earth systems, and a biological imaging and advanced photonics laboratory. Its completion would concentrate the Laboratory's programs in structural biology, biotechnology, human genome, global environmental studies, risk assessment and management, environmental restoration, social sciences, energy technologies for developing nations, energy efficiency, and transportation systems research.

Like the materials science divisions, research for environmental, life, and social sciences forces in 1992 was scattered throughout the Laboratory in older facilities. For example, the Biology Division had been housed since 1946 in obsolete facilities at the Y-12 plant, eight miles from the X-10 Laboratory complex. With much of the Laboratory's global research centered in the newly formed Enviornmental, Life, and Sciences Directorate, the collaborative interactions facilitated by concentrated research in this new complex would help open new horizons for the solution of global challenges.

One noteworthy problem area for the Laboratory lay in nuclear physics. Although the Holifield heavy ion research accelerator was only twelve years old in 1992, and set new records with beam energies in 1992 that were sixty percent higher than those achieved in 1982, it had fallen on hard times. New European accelerators provided even higher energies, and budget cuts reduced the operating time available for researchers at the Holifield accelerator. To reverse these trends, the Laboratory proposed to use the Holifield facilty to accelerate radioactive ion beams, a capability that would be unique in the world and thereby extend the facility's value to nuclear physicists. If this proposal is approved, a recoil mass spectrometer, jointly funded by the Laboratory and universities, would be acquired as a complementary device to the radioactive beam capability.

Although applying cost constraints to facilities such as the Holifield accelerator, the Department of Energy (DOE) began to devote vast resources during the 1990s to improving scientific understanding of the transport of wastes in the environment and the remediation of waste disposal sites. As a result, Trivelpiece expected the Laboratory to greatly expand its waste management and remediation fields.

If only some of these strategic plans bear fruit, the Laboratory's second half century promises to be as exciting as its first.

BACK TO THE FUTURE

As the Laboratory moved toward its second half century, Alvin Weinberg was preparing Wigner's papers for publication. His effort to uncover and organize the Laboratory's past gave Weinberg an opportunity to reflect on Wigner's legacy. The Laboratory's most renowned scientist not only set a standard of performance for Oak Ridge, Weinberg observed, but he also provided a vision of the future that speaks as directly to the uncertainties of the 1990s as it did to the uncertainties of the 1940s. In a simple statement of truth, Wigner once remarked, "Every moment brings surprises and unforeseeable events--truly the future is uncertain."

Weinberg himself viewed aging and the future with equanimity. He wryly concluded that scientists improve with age because their knowledge broadens as they become older. Much of science, he said, comes not out of brilliant flights of fancy but from viewpoints and techniques growing out of a lifetime of scientific inquiry.

The same sentiment might well apply to an institution that reaches the half-century mark. Its corporate experience and accomplishments should serve as a foundation of strength upon which to build a vigorous future of inventiveness and purpose.

Although the Laboratory, like science generally, seems more interested in the future than the past, it sometimes turns to its past for hope, inspiration, and understanding. When drafting plans for Laboratory initiatives during the 1990s, the strategic planning group admitted that improving national competitiveness through technology transfer and science education might be "more difficult than the Manhattan Project, which birthed the national laboratories nearly a half century ago."

In the 1940s, the nation's attention and resources were rivited on the war, and Laboratory efforts on behalf of the atomic bomb received the highest priority. Today, the enemies are less clearly defined and Laboratory initiatives must share the political spotlight with other government priorities and needs. This means the Laboratory will have to work even harder to justify public investment in its research activities. As Weinberg recently suggested, if the Laboratory is to become a prime engine of the national economy, its people must "adopt the same high standards and dedication shown during the four years of the Manhattan Project."

And so the experience of the Laboratory has come full circle. Amid the complex of buildings, intricate equipment, roads, reactors, accelerators, robots, piping, and test tubes, one force stands above all others in explaining the institution's success: the dedication of the people who work there. Ironically, that dedication reached its apex during the war years, when secrecy prevailed. Fifty years later, the Laboratory is determined to open its doors to the future, drawing on its storehouse of knowledge and skills to serve the public interest.

The purposes to which the Laboratory can now apply its talents are more diffuse. But for the Laboratory, the future has always been uncertain. Its staff has seized opportunities and redefined the Laboratory's purposes time and again to fit changing circumstances. As the Laboratory celebrates its fiftieth anniversary and as it stands on the threshold of the twenty-first century, there is little doubt that it will marshal its resources and talents to meet the challenges of tomorrow. At the dawn of a new era, this much is certain: if the Laboratory's past is its prologue, then its next fifty years should be as demanding, rewarding, and surprising as its first half century.

XX - DONE
AA - ASSIGNED
?? - NEED INFORMATION

WORKSHEET
SIDEBARS & PULLOUT QUOTES

CHAPTER 1

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3. TVA **(XX)**
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"It was as though we had discovered fire."
Richard Fox
Witness to first self-sustaining nuclear reactor at University of Chicago, December 2, 1942

"We had helped to do a bold and difficult job and had stopped a war in its tracks. That was enough for the moment. Second thoughts came later."
O.R. Physicist
August 1945

CHAPTER 2

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"Clinton will not live even if it is built up."
Robert Oppenheimer
January 1947

"Oak Ridge at that time was so terribly bureaucratized that I am sorry to say I could not stand it."
Eugene Wigner, 1947

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Moments/Places in Time

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1. A.Weinberg (AA)
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"I feel like my new job is a little bit like a trick horse-back rider at a circus. The idea seems to be to ride standing three or four spirited horses, all of which are interested in going in different directions."
Alvin Weinberg on his appointment to
Research Director - Late 1940s

"I am sometimes appalled by the size and scope of our operation here. It seems that we have become willy-nilly victims...of the big operator malady."
Alvin Weinberg
1953

"The (nuclear aircraft) program quite literally didn't get off the ground, but out of it grew the base for the high temperature materials technology needed by NASA and in several industrial fields."
George Adamson, ORNL Metallurgist
C. 1960

CHAPTER 4

Moments/Places in Time

1. Visiting the O.R. reactor/parade of VIPs JFK, Ford, etc. (AA)
2. 1955 Geneva Conference (??)
3. White Oak Lake (AA)
4. Chemical explosion in Thorex Plant Accidents? (AA)
5. Crossing the Swords **(XX)**

Personalities

1. Postma (AA)

Quotes

"It is not enough just to take this weapon out of the hands of the soldiers. It must be put into the hands of those who will know how to strip its military casing and adapt it to the arts of peace."
Dwight Eisenhower - Speech to United Nations
December 1953

"1954 has witnessed the transition that many of us have hoped for since the war. The increasing emphasis on peacetime applications of atomic energy has been a particular source of gratification."
Clarence Larson
1954

"Our Laboratory stands today as an institution of international reputation...But with international reputation comes international competition."
Alvin Weinberg
1955

"The biggest technological problem of our century: what reactor types will survive the test of experience--homogeneous, heterogeneous, circulating-fuel, boiling water, pressurized water, gas-cooled, sodium-cooled, fast or thermal? Will any one type emerge as the most economical stationary power plant reactor? Or will thermonuclear techniques overtake reactor development, and give us a solution to nuclear power technology without the nuisance of fission products? Time, money, effort, study, experience, and wise administration will give the answers, and new developments are fascinating to watch."
Arthur Snell
1957

"I Have received a letter from Chairman Strauss exhorting the Laboratory to do everything it possibly can to have incontrovertible proof of a thermonuclear plasma by the time of Geneva. We are now engaged in this enterprise; we have mobilized people from every part of the Laboratory for this purpose and, with complete assurance of unlimited support from the Commission, we have put the work into the very highest gear. I can think of few things that would give any of us as much satisfaction as to have Oak Ridge the scene of the first successful demonstration of substantial amounts of controlled thermonuclear energy."

Alvin Weinberg
1957 State of Laboratory speech

CHAPTER 5

Moments/Places in Time

1. ORNL and Kennedy assassination **(XX)**
2. Weinberg on value of lab Lab-Universities **(XX)**
3. Desalination-nuplexes (??)
4. Smoking mice (AA)
5. 1972 Aircraft Hijack (AA)
6. Kearny's field manual of survival (??)

Personalities

1. Women in the Lab (AA)
2. Minorities in the Lab (??)

Quotes

"What we should try to do is to identify long-range, valid-missions which in scope and importance are suitable for prosecution...Most missions of this sort will probably not fall in the field of nuclear energy. This need not bother us since in the very long run ORNL very possibly will not be in nuclear energy exclusively."

Alvin Weinberg
1961

"Solving today's social and economic problems with tomorrow technology is risky."

Alvin Weinberg
1970

"I never expected to see the thread of life, the mysterious stuff that poets conjured long ago to explain the passage of the heartbeat from generation to generation across the ions. Yet today, the thread lies clearly visible before me, under the lens of an electron microscope, here in the Tennessee hills."

John Lear
Saturday Review of Literature, 1967

"We in Oak Ridge, living as we do in a sheltered and pleasant scientific Lotus-land, just don't know what our colleagues in the beleaguered universities are up against."

Alvin Weinberg
1969

CHAPTER 6

Moments/Places in Time

1. The Lab's reaction to Earthday (AA)
2. ECCS (AA)
3. "The Nation's Energy Future" (AA)
4. Heavy-section steel (??)

Personalities

Quotes

"Nuclear energy in fact any energy, in the United States simply must come to some terms in the environment."
Weinberg
C. 1972

Laboratory veterans longed for the days when "what we did at the ORNL was separate plutonium, measure cross sections, and develop instruments for detecting radiation action."
Weinberg
1971

"The Laboratory is now in uniquely strong position to undertake a multimodel attack on the nation's energy problems."
Floyd Culler
1973

Nuclear people have made a Faustian Contract with society; we offer an almost unique possibility for a technologically abundant world for the oncoming billions, through our miraculous, inexhaustible energy source; but this energy source at the same time is tainted with potential side effects that if uncontrolled, could spell disaster.
Weinberg
1971 (??)

"The best morale builder is for a man to have more work to do than he can possibly get done. The problem with any of us being idle is that we won't go off in a corner by ourselves to spend our idle time along; abut instead, we go to someone who may be busy and talk with him. Then, likely as not, we will talk about what is wrong with the place instead of what is right about it."
Leon Love, "The Early History of the Electromagnetic Separation of Large Quantities of Stable and Radioactive Isotopes
MS, Oak Ridge,
1991 p. 53

"We generally think of science and technology curricula in terms of university programs, but the scientist usually selects at least the broad field of scientific endeavor at the high school level. If we are to continue our remarkable technological growth, which has become the cornerstone of our American way of life, we must have more scientists and engineers which means we must interest more high school students in these fields."

Robert Charpie,
1956 "What Makes a Scientist Tick?"

"In the long run the greatest benefit that humanity will receive from science will come from the biologist, not from the physicist and engineer. I would hope that our country and Congress can be educated to understand that biology, rather than physics, will give the more important answers to the problems of human want and human happiness, and that biology therefore deserves support on a much vaster scale than it now receives."

Alvin Weinberg
January 16, 1958

America is a pluralistic society. Our strength has lain in our variety of approaches, our diversity of institutions, all striving to improve the human condition. Sot it is with basic research: it can flourish in many settings and in many places. History has shown that it does well indeed in our setting and in our somewhat out-of-the-way and possibly unlikely location."

Alvin Weinberg
1965 from State of Laboratory

CHAPTER 7

Moments/Places In Time

1. President Carter visit, May 1978 (AA)
2. National Environmental Research Park, est. 1980 (AA)
3. User facilities (??)
4. Walker Branch Watershed (AA)

Personalities

Herman Postma (AA)
Alex Zucker (AA)

Quotes

"Our decision about energy will test the character of the American people and the ability of the President and the Congress to govern this nation. This difficult effort will be the moral equivalent of war--except that we will be uniting our efforts to build and not to destroy."

President James Carter
April 18, 1977

"It is one of the functions of a scientific laboratory to discover the unexpected, to develop new ideas, and to explore in an unfettered way areas that may not show much promise to the casual observer."
Alex Zucker
1978

"Oak Ridge was almost like Mecca for us because this is where the basic work was done that, first of all, contributed to the freedom of the world and ended the war and, secondly, shifted very rapidly to peaceful use of nuclear power."
President James Carter
May 1978, recalling his service with the nuclear Navy.

CHAPTER 8

Moments/Places In Time

1. 1982 Knoxville Worlds Fair, ORNL Overlook, tours (??)
2. Union Carbide replaced by Martin Marietta, 1982-1984. (??)
3. Postma speaks with Reagan at UT Knoxville, Sept. 24, 1985. (??)

Sidelights

1. Roof Research Center (AA)

Personalities

Quotes

"One of the important roles of the national laboratories is that the labs provide a continuity of effort and strength in the midst of continual change. They act as a repository, perhaps the last repository, for corporate memory in energy research and development."
Herman Postma
1982

"Union Carbide Corporation has informed the Department of Energy of its intention to withdraw as the contractor. The decision not to renew the contract is based on Union Carbide's strategy of concentrating its resources and management attention on those commercial businesses in which it has achieved a leadership position."
Roger Hibbs
May 3, 1982

"The essence of a laboratory is that it experiments, it explores, it hurls itself against the limits of knowledge. In short, it tries. Often it fails."
Herman Postma
1983

Sidelights

CHAPTER 9

Moments/Places in Time

1. President Bush visits ORNL, February 19, 1992 (AA)

Personalities

1. Alvin Trivelpiece (AA)

Sidelights

1. Zachery Taylor analysis, 1991. (AA)

Quotes

"We have transformed the arsenal of democracy into the engine of economic growth."
President George Bush
February 19, 1992

"The United States must develop an infrastructure that creates and nurtures a world-class education system."
Alvin Trivelpiece
April 1991

"Science is well recorded. It gets written down and can be read years later and can be continued by other scientists. That is not true when it comes to technology. In matters of technology, problems are solved by people getting together, discussing them and coming up with a solution. In other words, science is usually transferred by journal articles, but technology transfer is word-of-mouth, people-to-people.
George Adamson - Metallurgical Engineer
1985, quoted in The Oak Ridger

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